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# SINTEF REPORT

TITLE

# Technical Documentation for the Pipeline Oil Spill Volume Computer Model

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CLIENT(S)

U.S. Minerals Management Service

| REPORT NO. | CLASSIFICATION | CLIENTS REF. | |
|---|---|---|---|
| STF66 A03015 | Unrestricted | Sharon Buffington | |
| **CLASS. THIS PAGE** | **ISBN** | **PROJECT NO.** | **NO. OF PAGES/APPENDICES** |
| Unrestricted | 82-14-03031-5 | 661247 | 45 |

| ELECTRONIC FILE CODE | PROJECT MANAGER (NAME, SIGN.) | CHECKED BY (NAME, SIGN.) |
|---|---|---|
| WCD Tech Description_final-170203.doc | Mark Reed | Henrik Rye |

| FILE CODE | DATE | APPROVED BY (NAME, POSITION, SIGN.) |
|---|---|---|
| | 2003-01-20 | Tore Aunaas |

ABSTRACT

This report describes the technical background and content of the MMS Pipeline Oil Spill Volume Computer Model (POSVCM). The software is designed to estimate the amount of oil that leaks out of an underwater pipeline following a break, crack or other damage. The tool also includes a nearfield module that provides an estimate of the thickness of the resulting oil slick at the sea surface.

The primary computational modules, the release and nearfield components, are described in detail, as is the connection between the POSVCM and the MMS Pipeline Information Database. Tests of the model against documented pipeline breaks have been carried out. The results are also included here.

| KEYWORDS | ENGLISH | NORWEGIAN |
|---|---|---|
| GROUP 1 | Offshore, Environment, Oil Spills | |
| GROUP 2 | Marine environmental model | Marint miljø |
| SELECTED BY AUTHOR | Seafloor pipelines, leaks | Undervanns rørledninger, lekkasjer |
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# TABLE OF CONTENTS

# 1 Introduction

The Minerals Management Service Pipeline Oil Spill Volume Computer Model (POSVCM) is a computer-based methodology to determine worst case discharges from seafloor pipelines.

Inputs to the POSVCM are parameters describing the configuration and characteristics of a pipeline, the fluid it contains, and the leak or break from which the discharge occurs.

Key outputs are the evolution of the release rate over time, the total mass of oil released, and a measure or the mean thickness of any eventual surface slick being formed.

The system is composed of a Release Module and a Near Field Module, linked together with necessary databases through a Graphical User Interface (GUI), as shown in Figure 1. (The bathymetric database is not implemented in Version 1.0 of POSVCM.)

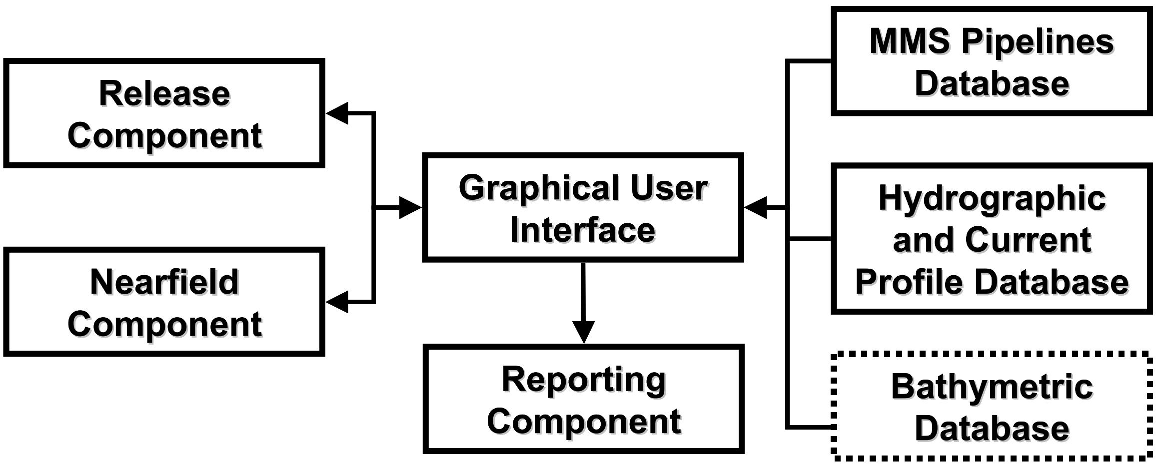


*Figure 1. Schematic of the MMS Worst Case Discharge Software*

# 2 Graphical User Interface (GUI)

The GUI for the MMS POSVCM Software has been programmed in C++, and has been built around the free software Dia. The most recent version of this software can be downloaded from the Dia homepage (http://www.lysator.liu.se/~alla/dia/). A tutorial on use of the software is also available on the Internet ( http://www.seanet.com/~hgg9140/comp/diatut/all/all.html ). The complete code for the interface is available from MMS, including direct link libraries for the Release and NearField Modules.

# 3 Release Module

The Release Module consists of two different models; the *Black Oil* fluid property model, which calculates the necessary fluid properties, and the *Dynamic flow simulation* model which handles the transient two-phase flow calculations. The two models are described below.

## 3.1 Black Oil Fluid Property Model

The *Black Oil* model (McCain, 1990) consists of well-known correlations used to determine the physical fluid properties at different pressures and temperatures. The Black Oil correlations have been programmed and included in the POSVCM model as part of the Release module.

The assumptions in the *Black Oil* model are that, at any fixed temperature, pressure, API gravity of the liquid phase and specific gravity of gas, the liquid phase has a fixed gas solubility and formation volume factor. These assumptions imply that the composition of the oil and gas do not change with pressure and temperature.  An important limitation of the *Black Oil* model is its inability to predict retrograde condensation phenomena. The *Black Oil* model is therefore not appropriate for very volatile oils and light crude oil or gas condensates. The model is based on a number of oil samples with densities ranging from 16 to 60 °API and gas-oil-ratios from 20 to 2500 scf/stb. The accuracy of the model will decrease if used outside these ranges.

When the density of the liquid phase, the density of the gas phase and the gas-oil volume ratio (GOR) at standard conditions are known, the *Black Oil* model can be used to calculate the following physical fluid properties at any pressure and temperature:

- Density of gas and oil,
- Compressibility for gas and oil,
- Thermal expansion for gas and oil,
- Gas solubility,
- Viscosity of gas and oil,
- Heat capacity for gas and oil,
- Enthalpy for gas and oil,
- Gas and oil thermal conductivities,
- Surface tension between gas and oil.

### 3.2 Dynamic Flow Simulation Model

This model is a transient two-phase flow model based on conservation equations. Two separate mass and momentum equations for gas and liquid and one energy equation. Two phase flow is much more complex than single-phase flow. The effect of different flow regimes, velocity differences between the gas and the liquid phase and the fact that gas will flash from the liquid as the pressure decreases complicate the calculations.

Estimation of rates is based on flashing, integration, choking effects and fluid flow behavior in the system. Total volume released is calculated from:

- Rate variation and release time,
- Leak detection time and production rates,
- Shutdown time for each component in the system,
- Location of rupture, and
- Flashing in the system.

#### 3.2.1 Data requirements

To provide the release results, the software needs the following information:

- Geometrical description of the flow lines
- Physical properties of the hydrocarbon fluid
- Receiving pressure at the outlet of the system
- Leak position and size

#### 3.2.2 Geometrical discretization

Pipeline length and diameter must be specified. It might be of importance to specify dips and peaks along the pipeline where liquid could accumulate. Generally, finer grid results in more accurate calculations. Each user specified pipeline is discretized into a number of sections in the model and calculations are done for each of the section elements in the system. The computational time increases with the number of sections, and a short single pipeline is much faster to simulate than a complex network with many internal sections.

#### 3.2.3 Leak modeling

The leak/rupture in a pipeline is modeled by implementation of a critical choke model with a diameter equal the equivalent diameter of the leak. Typical explicit choke flow models included in the Dynamic flow simulation model are Gilbert, Ros, Baxendall, and Achonge.

These correlations are all of the form:

$$Q = a \cdot P_{up} \frac{d_{choke}^{c}}{GLR^{b}}$$

where

| | |
|---|---|
| $P_{up}$ | upstream pressure of choke (psi) |
| $Q$ | liquid production rate (bbl/d) |
| GLR | Upstream gas liquid ratio (scf/stb) |
| $d_{choke}$ | choke size in 64th's of an inch (-) |

The empirical coefficients, a,b,c are given in the table below:

*Table 3.1: Empirical coefficients used for critical leak modelling*

| Correlation | a | b | c |
|---|---|---|---|
| Gilbert | 0.1 | 0.546 | 1.89 |
| Ros | 0.05747 | 0.5 | 2.00 |
| Baxendall | 0.1046 | 0.546 | 1.93 |
| Achonge | 0.26178 | 0.65 | 1.88 |

The default correlation used by the software is the model after Ros. Other correlations can easily be implemented for future use. For a small rupture or leak the maximum outflow rate is dependent on the critical mass flow rate through the leak. For a large rupture or total break of the pipeline the maximum outflow rate is dependent on the fluid flow inside the pipeline and the pressure drop in the pipeline. The flow through the choke at any time point can be gas, oil or a mixture depending on the fluid in the pipe segment.

### 3.2.4 Flow Regimes

When two phases flow simultaneously in pipes, the flow regime, pressure- and velocity fields are strongly connected. The phases tend to separate because of differences in density. Perhaps the most distinguishing aspect of multiphase flow is the variation in the physical distribution of the phases in the pipe, a characteristic known as flow regime. During two-phase flow in pipes, the flow pattern that exists depends on the relative magnitudes of the forces that act on the fluid. Buoyancy, turbulence, inertia and surface tension forces vary significantly with flow rates, pipe diameter, inclination angle, and fluid properties of the phases. Several different flow regimes can exist in a pipe as a result of the large pressure and temperature changes the fluids encounter. The estimation of the void fraction (and liquid holdup) in combination with flow pattern predictions are the major challenge in two phase flow calculations.

It is common to distinguish between flow in horizontal and vertical pipes. Figure 3.1 and Figure 3.2 show schematic drawing of flow regimes in vertical and horizontal pipes respectively. The entirely different nature of these flow regimes affects the pressure drop in the pipeline and also the total volume released.

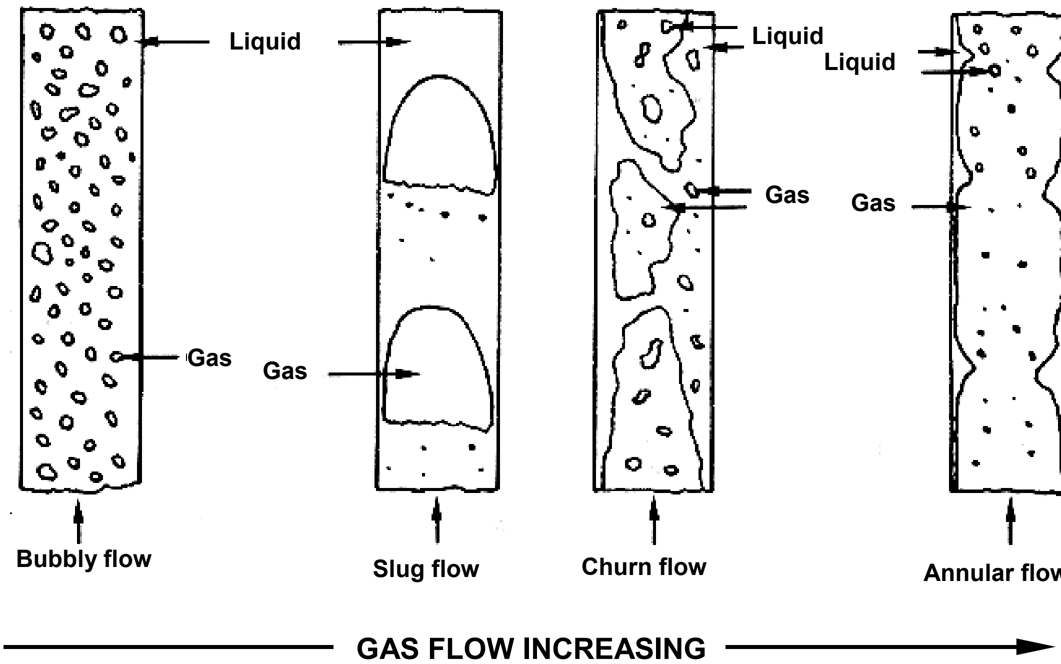


*Figure 3.1 Schematic drawing of vertical flow regimes*

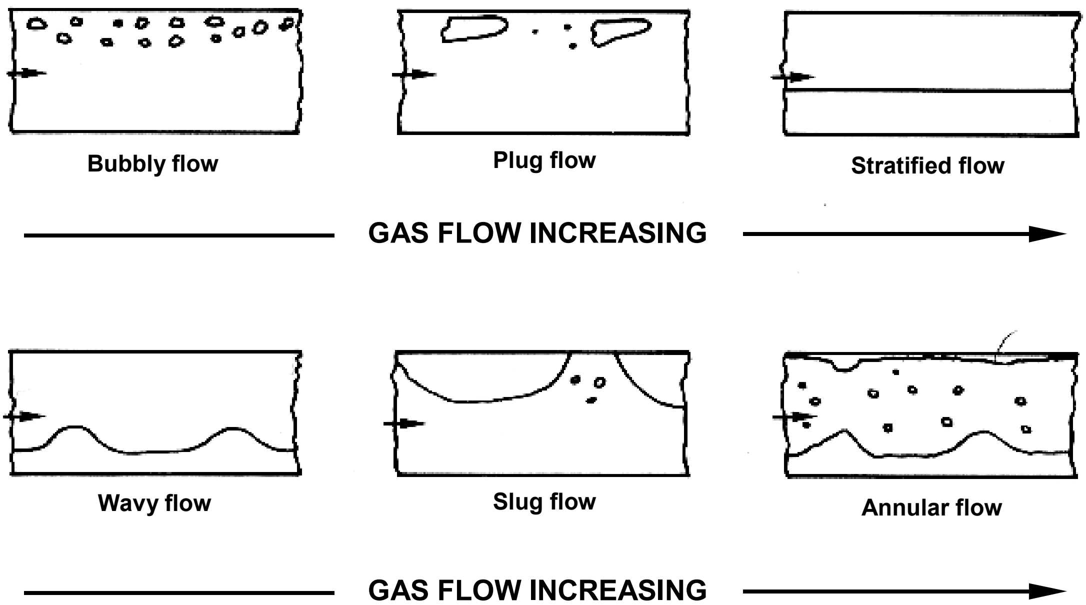


*Figure 3.2 Schematic drawing of horizontal flow regimes*

### 3.2.5 Definition of phases and slip velocity

The model operates with two phases gas and oil (or oil water mixture). These two phases travel with different velocities. In general the gas in the pipeline moves faster than the liquid because of its lower density and viscosity. The ratio of the average gas and liquid phase velocities is referred to as slip or slip ratio.

$$\text{Slip} = \frac{\text{Average gas velocity}}{\text{Average liquid velocity}} \qquad \textit{(Eq. 3.1)}$$

There are different methods used in the literature to estimate this slip ratio, which in turn is used to calculate liquid holdup or gas void fraction. The estimation of the flowregime and liquid holdup is required in order to calculate a correct pressure drop. One correlation that has been used widely in the industry is based on the total kinetic energy, and the assumption that the phases will tend to flow with this at its minimum. Zivi (1964) showed that using this assumption, the slip is only dependent on the density ratio between the phases. More advanced correlations include the dependencies on more properties, like viscosities, gas mass fractions, diameter and surface tension.

In the POSVE, the Martinelli's correlation is used to calculate the liquid fraction in the pipeline. The liquid holdup is a function (by empirical correlations, see references) of the Martinelli parameter which is defined as:

$$X = \left[ \frac{(dp/dz)_l}{(dp/dz)_g} \right]^{1/2}$$

where

| | | |
|---|---|---|
| $(dp/dz)_l$ | - | frictional pressure gradient if liquid were flowing alone in the pipe |
| $(dp/dz)_g$ | - | frictional pressure gradient if gas were flowing alone in the pipe |

### 3.2.6 Nomenclature for a pipeline layout

The physical elements used to define a pipeline layout in POSVCM are as follows:

| | | |
|---|---|---|
| Pipe | - | an element with a given diameter, length, height, roughness and u value |
| Branch | - | one or more connecting pipes in series (Figure 3.3) |
| Connection | - | connects two pipes |
| Junction | - | connects two or more braches. |
| Network | - | two or more connected branches (Figure 3.4) |

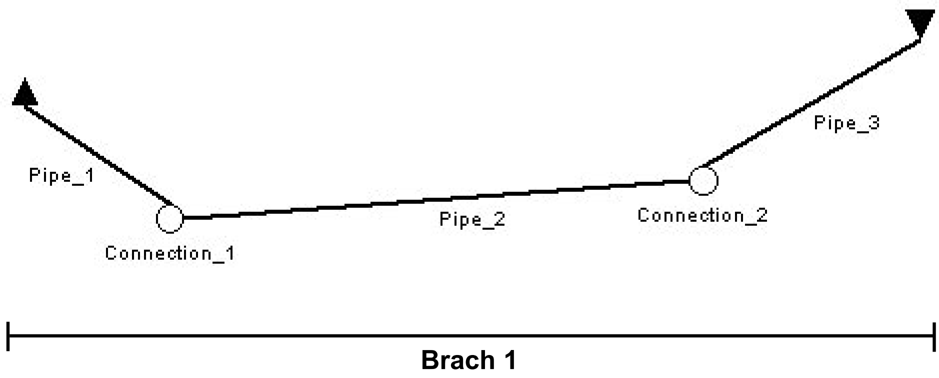


*Figure 3.3 Example sketch of a branch*

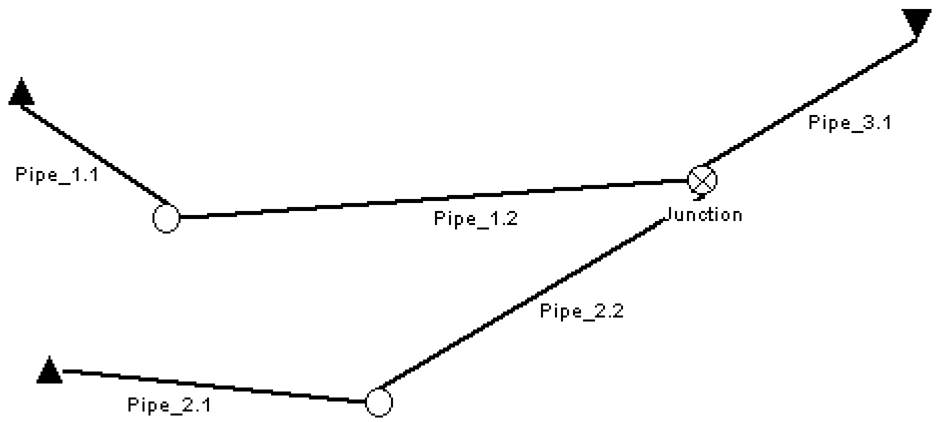


*Figure 3.4 Example sketch of a network*

A network can only have one outlet and one leak/rupture, but may have several inlets.

# 4 Near field module

The Near Field Module consists of two models linked together in a single program, the oil and gas plume simulation model *DeepBlow* and the *Surfacing* model simulating the formation of surface slicks from oil droplets escaping from the plume. The two models are described below.

## 4.1 Plume simulation model (DeepBlow)

SINTEF has developed a multiphase integral plume model for simulations of the near-field behavior of deepwater blowouts. A comprehensive description of the *DeepBlow* model is given in a recent paper (Johansen 2000), but some of the major features of the model are summarized here.

The *DeepBlow* model was developed in response to the increasing interest in petroleum exploration in deep waters, both in Norway and internationally. In this conjunction, deep water implies water depths from 500 to more than 1200 meters. Previously, when releases from more shallow depths were concerned, sub sea blowouts have been modeled as buoyant plumes in stagnant waters, where the buoyancy was mainly related to the gas released at or near the sea bed. However, blowouts from deep waters will behave significantly different in many major aspects:

- For blowouts at shallow to moderate depths the gas may be considered as an ideal gas with a specific volume decreasing linearly with pressure. The volume flux of gas at any depth may then be derived from the gas-to-oil volume ratio at standard conditions (GOR). However, when the blowout takes place at greater depths, the gas can no longer be presumed to behave as an ideal gas, and a pressure and temperature dependent compressibility factor (*z*-factor) must be introduced in the pressure-volume relationship. This normally implies that the specific volume of the discharged gas will be less than predicted by the ideal gas law.

- At the same time, the fraction of gas dissolved in the oil will increase with pressure. This implies that the vapor mass fraction of the well flow at the outlet will be reduced compared to the mass fraction predicted by the GOR.

- Dissolution of gas from rising bubbles into ambient water may be negligible for blowouts at shallow to moderate depths, since the residence time of the gas bubbles is expected to be short. For blowouts from deep waters — when the rise time of the gas bubbles may be expected to be significantly longer and the solubility of gas in sea water is increased due to larger ambient pressures — a significant reduction in the buoyancy flux may be expected due to dissolution of gas in sea water.

- In addition, natural gas tends to form gas hydrates at elevated pressures and low temperatures. Thus, when a blowout takes place at large depths, the gas may be converted to hydrate in contact with cold bottom water. If that happens, the contribution of the gas to the buoyancy flux will vanish, and the considerably smaller buoyancy caused by gas hydrates and oil will instead drive the rise of the plume.

Together, these factors will cause a significant reduction in buoyancy flux, and as a consequence, the plume may become more sensitive to cross currents and the presence of density stratification in the water masses. In such cases, even small stable density gradients in the ambient water may be expected to cause trapping of the plume. However, the oil may finally arrive at the sea surface due to the buoyancy of individual oil droplets. The resulting surface spreading of the oil will then depend on the size distribution of the oil droplets and the strength and variability of the ambient current.

This situation differs significantly from the situation when blowouts occur at moderate depths. In such cases, the surface spreading of the oil will be governed by the radial outflow of water entrained by the rising gas bubble plume. This implies that without major modifications, existing blowout models will produce unrealistic predictions of plume behavior and surface spreading when applied to blowouts from deep water. As a consequence, in the *DeepBlow* plume model developed by SINTEF, the following major factors have been taken into account in addition to factors included in blowout plume models in general:

- Effects of cross currents and ambient stratification
- Non-ideal gas behavior
- Dissolution of gas and hydrate formation

The first modification (effects of cross currents) implies in the first place the introduction of the mechanism of forced entrainment in the model. However, when this is included, the plume may be found to bend over due to entrainment of momentum from the ambient water. This implies a potential for leakage of gas bubbles from the plume, which has been accounted for in the model.

The second modification (non-ideal gas behavior) implies introduction of a pressure and temperature dependent compressibility factor (*z*-factor) in the pressure-volume-temperature (PVT) relationship of the gas. This *z*-factor depends in addition on the composition of the gas phase, and is a well-known subject in petroleum physics.

The last modification implies that the potential conversion of gas into hydrate in contact with seawater must be introduced in the model. At the same time, the buoyancy of hydrates formed from the gas must substitute the buoyancy of the gas bubbles. Gas that does not form hydrate must be allowed to dissolve in the water masses, causing a corresponding loss in buoyancy from the gas. While the thermodynamic condition for hydrate formation is well established, it is still uncertain whether hydrate formation will actually take place, and if that happens - at which rate the gas bubbles will be converted into hydrate. In order to take this uncertainty into account, hydrate formation may be turned on or off in the model to demonstrate the sensitivity of the results to this process.

Once the underwater plume has reached the layer where the plume is entrapped (density of the plume equals the density of the ambient water), the oil droplets will tend to rise out of the underwater plume. The oil droplets will then rise to the sea surface, dependent on their rise velocity (droplet size dependent). The droplets will appear at the sea surface, dependent on their sizes and the ambient currents. The droplet sizes govern the rise velocity and thus the time for the oil droplet spent on the ascent. The ocean currents will govern the location where the oil droplets will appear at the sea surface. On the other hand, the plume may also come to the surface, and in this case, the spreading of the surface oil will be governed by the radial outflow of the entrained water, as explained in the next section.

### 4.2 Surface slick formation

When the results from the *DeepBlow* model are used to initialise the slick formation, two different cases are distinguished (see Figure 4.1): the plume is coming to the surface (case a), or the plume is trapped at an intermediate depth (case b).

*Surfacing plumes*: When the plume reaches the sea surface, the entrained water will be forced into a radial flow and bring with it the dispersed oil droplets. The strength of this radial flow is expressed in terms of the source strength $s$ determined from the plume radius and rise velocity by the following equation (Fanneløp and Sjøen, 1980):

$$s = \pi \left( \frac{2\sqrt{2}}{\beta} \right)^{1/2} b\, v \qquad \text{(Eq. 4.1)}$$

where $b$ and $v$ is the radius and velocity of the plume[1] as it approaches the surface, while $\beta$ is an entrainment coefficient ($\beta = 0.06$). Fanneløp derived this expression for a vertical plume, and to account for plumes that approach the surface in an angle different from 90 degrees, the plume velocity $v$ has been replaced by $v = \sqrt{u\,w}$, where $u$ is the axial plume velocity, while $w$ is the vertical component of the plume velocity. Note that the condition $w = u$ will apply to vertical plumes, while the condition $w < u$ will apply to inclined plumes.

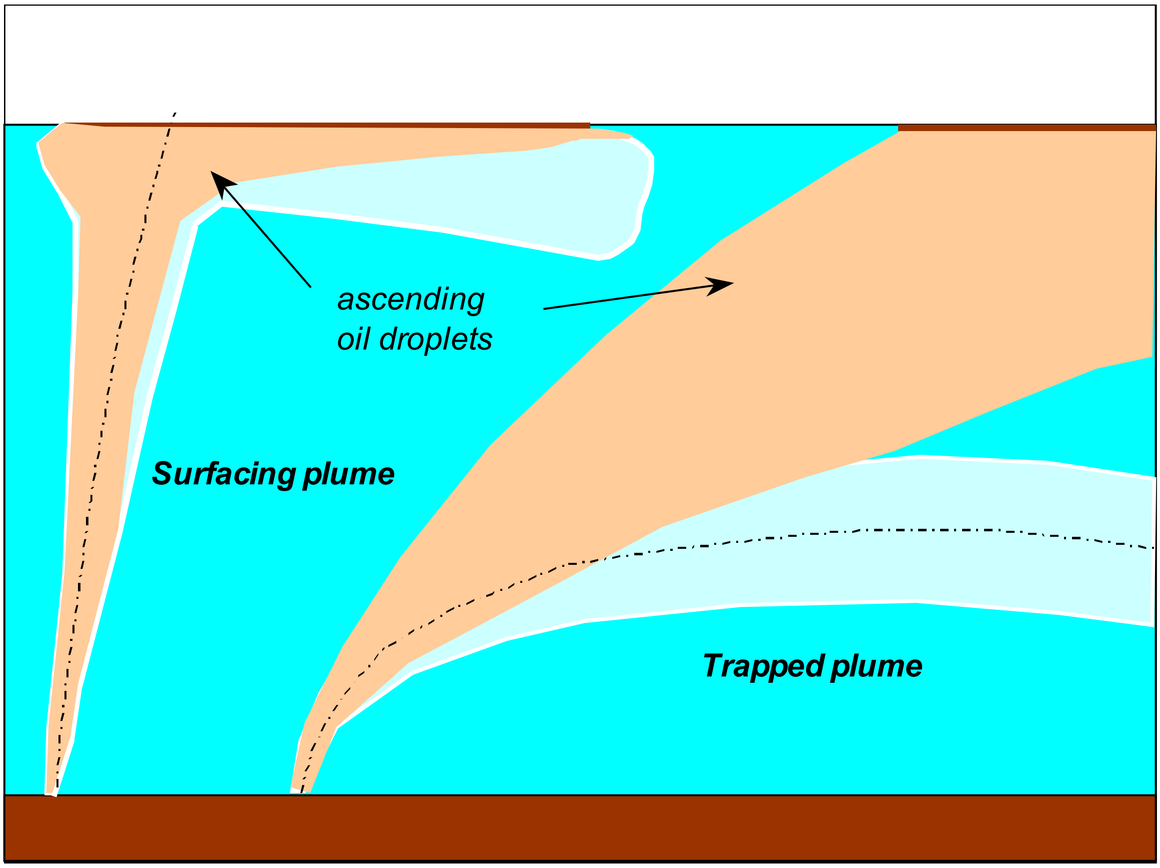


*Figure 4.1 Principal sketch of two possible results from the plume model and the corresponding initialisation of the oil droplets in the oil drift model. See text for explanations.*

The source strength determines the radial velocity in the surface flow at a given radial distance $r$ from the point where the plume comes to the surface:

[1] The plume parameters $b$ and $v$ is output from the DeepBlow model

$$U_r = \frac{s}{2\pi r} \qquad \text{(Eq. 4.2)}$$

In this case (surfacing plume), this radial velocity component is superimposed on the ambient current in the subsequent computations of the drift of the oil.

*Trapped plumes*: When the plume is trapped at intermediate depths between the seabed and the sea surface, the oil droplets are supposed to rise with their own terminal velocity, which is superimposed on the plume rise velocity below the level where the plume rise terminates (depth of trapping). In the rise time, the droplets are moved horizontally by the ambient current, which may vary with depth and time.

The *DeepBlow* model includes an estimate of the droplet size distribution based of the conditions at the exit point. The model distinguishes between two different exit situations:

a) Oil dispersed as droplets in a gas flow (mist flow).
b) Gas present as bubbles or slugs in a continuous gas phase (oil jet).

The maximum droplet size (e.g. $d_{95}$) is in both cases related to the exit diameter $d_0$ and the dimensionless Weber number We (Rye et al 1998):

$$d_{95} = k\, d_0\, \mathrm{We}^{-0.6}, \text{where We} = \frac{v_0^2\, d_0\, \rho}{\sigma} \qquad \text{(Eq. 4.3)}$$

In the expression for the Weber number, $v_0$ is the exit velocity. The value of the coefficient $k$ and the physical parameters (density ρ and interfacial tension σ) is different in the two cases, as given in Table 4.1. Note that for the mist flow case, the coefficient $k = 4$ is established empirically from numerous pipe flow experiments (Karabelas 1978). For oil jets, the same form of equation is used, with the coefficient $k = 20$ chosen to match the observations from the DeepSpill experiment (Johansen et al. 2001). This is a provisional solution, chosen due to the lack of relevant experimental data on droplet size formation in large flow liquid-liquid jets.

Table 4.1 Parameters in droplet size (Eq. *4.4*):

| Parameter | a) Mist flow in pipe | b) Oil jet in water |
|---|---|---|
| Coefficient $k$ | 4 | 20 |
| Density of continuous phase, ρ | Density of gas | Density of water |
| Interfacial tension, σ | Gas – oil (≈0.005 N/m) | Oil – water (≈0.03 N/m) |

Note also that the interfacial tension between oil and gas may vary significantly depending on pressure and temperature (McCain 1990, pp. 334 – 338), while the indicated value of 0.03 N/m for interfacial tension between oil and water is representative for most crude oils.

The actual droplet size distribution is computed from the Rosin-Rammler distribution (Lefebvre 1989). This implies that the fraction of the total oil volume contained in droplets with diameter less than $d$ is then given by the equation:

$$V(d) = 1 - \exp\left[-2.996\left(\frac{d}{d_{95}}\right)^p\right] \qquad \text{(Eq. 4.5)}$$

where the spreading exponent is chosen as $p = 2.5$.

The rise velocity of the oil droplets is computed from the diameter $d$ and the density of the oil relative to seawater by the following equations:

Small droplets (Re < 1): $$w = \frac{d^2}{18\nu} g' \qquad \text{(Eq. 4.6)}$$

Large droplets (Re >1000): $$w = 1.8\sqrt{d\, g'} \qquad \text{(Eq. 4.7)}$$

In these equations, $\nu$ is the kinematic viscosity of seawater, while $g'$ is the so-called reduced gravity, defined as $g' = g(\rho_w - \rho_{oil})/\rho_w$. In order to account for droplets of all sizes, the following interpolation scheme has been applied:

$$w = 1/(w_1^{-1} + w_2^{-1}) \qquad \text{(Eq. 4.8)}$$

where $w_1$ and $w_2$ are the values computed by the equations for small and large droplets.

### 4.3 Implementation

As mentioned above, the Near Field module contains both the oil and gas plume model and the surfacing model in an integrated model system. Input data defining the discharge are obtained from the Release Module, but ambient data, such as hydrographical data (vertical sea temperature and salinity profiles) and ocean currents are also required to run the model. Also, some specific simulation parameters have to be given by the user to run the model.

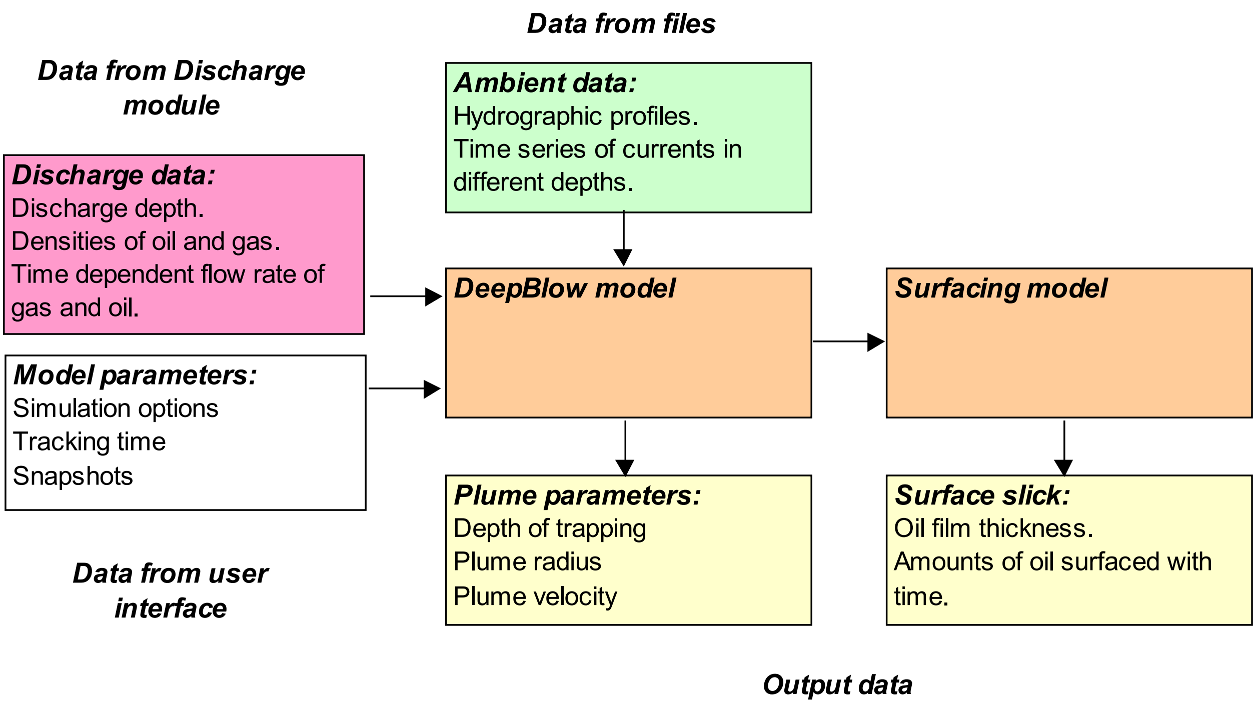


*Figure 4.2 Principal sketch of main components of Near Field Module.*

The output from the plume model includes a detailed description of the plume geometry and composition in addition to a summary of the results from the plume simulations (depth of trapping etc). The output from the surfacing model includes a detailed description of the development of the surface slick with time, in addition to a summary of the main results in terms of amounts of oil surfaced and average oil film thickness as a function of time.

The Release Module produces time dependent flow rates of oil and gas together with some physical characteristics of the oil and gas (density, interfacial tension). The plume model simulates this time dependent discharge in terms of a series of discharges, each with fixed discharge rates corresponding to the mean discharge rates in the respective time intervals. An example is shown in Figure 4.3 where high initial discharge rates of oil and gas cause the plume to surface. Subsequently, the plume is trapped by the density stratification in the water masses due to a continuous reduction in the discharge rates.

The time intervals are chosen to correspond to the time intervals in the available ocean current data. The Surfacing model uses the results from each of these plumes to form a continuous oil slick on the sea surface (see Figure 4.4).

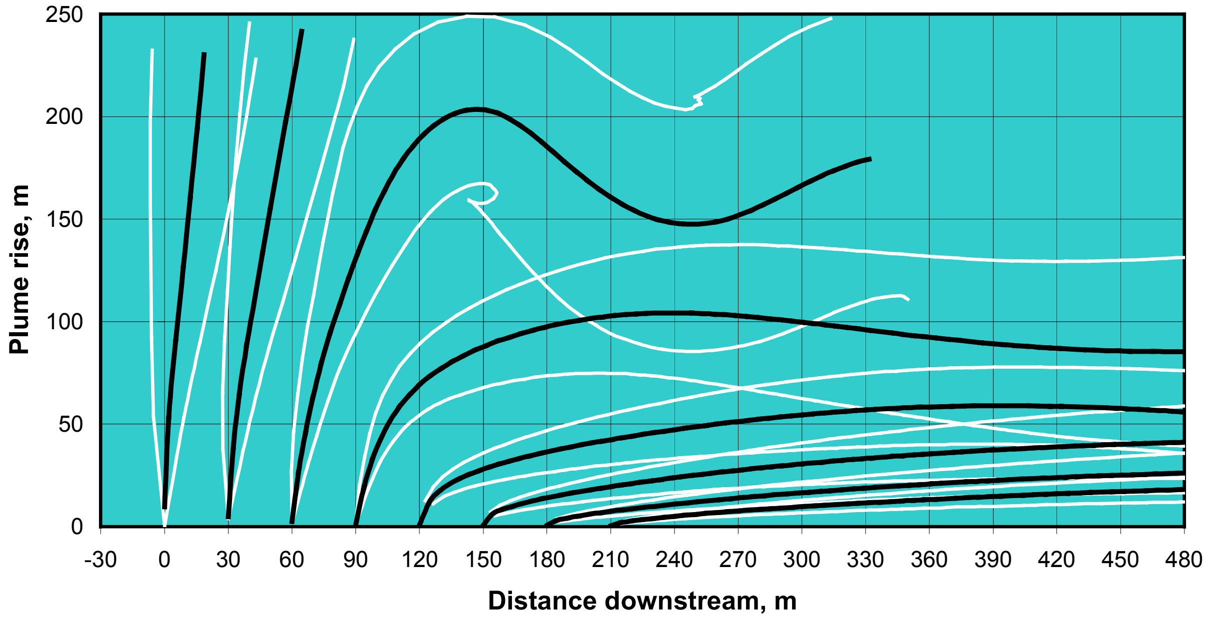


*Figure 4.3 Example of plume trajectories computed for a time dependent discharge of oil and gas. Solid lines represents plume centrelines, while white lines indicate the width of the plumes. The discharge is represented by distinct plumes simulated each half hour. Each trajectory is shifted 30 m downstream to make the results more readable.*

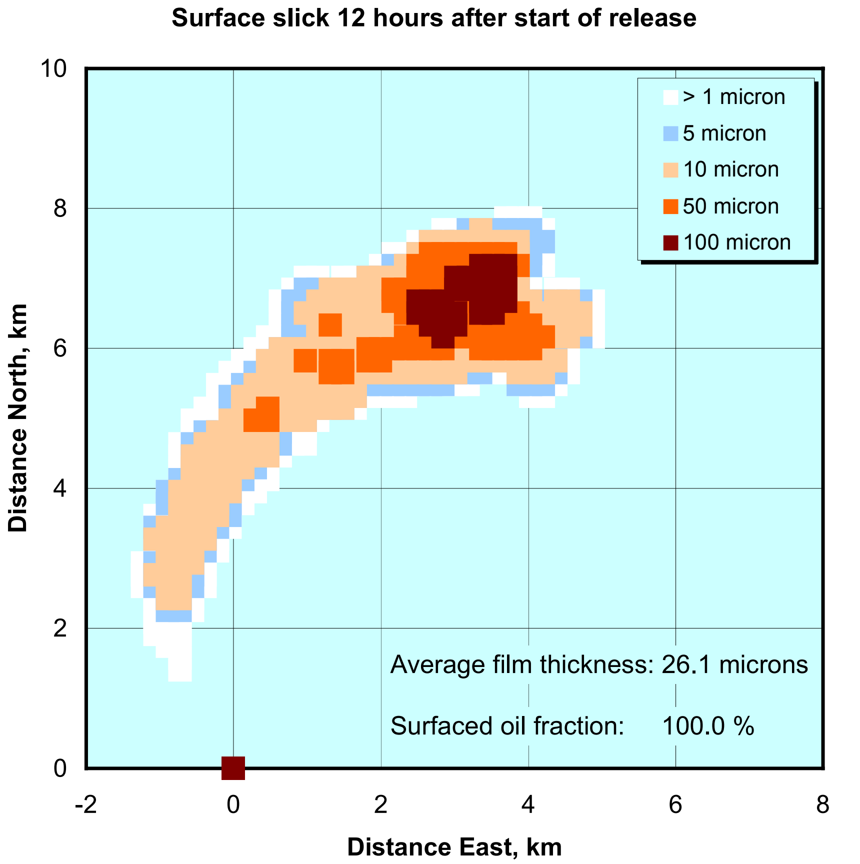


*Figure 4.4 Example of surface slick formed from a time dependent discharge of oil and gas lasting for 9 hours.*

## 4.4 Description of input data files for the Nearfield module

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**(a)**

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      0.00        8.72       10.16        8.59       10.47       10.85        8.49        8.37        8.46       11.20        8.85
      0.05       10.79        9.90        9.41        9.25       11.65        8.12        9.68        9.93       11.09        8.22
      0.10        9.97       11.44       10.96        9.20       12.35        8.28        8.79       11.67       12.63        7.17
      0.15       11.27        9.98       12.43        9.30       14.16       10.21        9.74       12.74       12.31        7.78
      0.20       11.84       11.35       12.92        9.79       14.56       10.45       10.39       11.67       12.05        8.37
      0.25       12.05       11.43       11.97       11.19       14.50       10.45        9.83       10.65       13.44        9.18
      0.30       12.31       11.65       11.89       11.96       14.61       11.91        9.20       10.56       13.78       10.14
      0.35       11.07       10.71       12.81       11.11       14.58       13.83        9.16       10.07       14.47        9.65
      0.40       10.74        9.83       14.62       12.53       14.57       14.13        9.23       11.22       15.79       10.31
      0.45       11.30       10.89       14.08       11.64       14.86       16.01        8.87       10.44       16.29        8.99
      0.50       10.56       12.27       14.01       11.51       15.94       17.65       10.79       10.41       16.26        8.97
      0.55       10.16       10.85       15.37       10.40       14.57       16.98       10.72        9.68       15.63        9.67
      0.60        9.74       11.98       16.35       11.72       15.19       16.89       10.67       11.75       16.01        9.77
      0.65        8.48       12.12       17.75       13.76       15.00       16.33       11.62       12.92       14.63        9.98
      0.70        9.87       13.31       19.24       13.37       15.07       17.67       13.44       13.23       16.47        9.64
```

**(b)**

ThreeMin.AHP - Notepad

File Edit Format Help

```
  5.00  8.50 35.00 Blokk 7122/7 August (PL 229)
 12.50  8.40 35.00
 25.00  8.30 35.00
 37.50  7.70 35.00
 50.00  7.50 35.00
100.00  6.20 35.00
150.00  5.70 35.00
200.00  5.50 35.00
450.00  5.30 35.00
```

**(c)**

*Figure 4.5 Input file formats for vertical current and hydrographic data for the Near Field module. Figures (a) and (b) show the North and East velocity component files. The first row gives the number of depth intervals (10 in this example), the total depth (300 m here), and the time step between subsequent records (0.05 hr, or 3 min here). The second row is the start time with time in hours from the reference date January 1, 1900, in the first column, and the depths of the measurements following. Subsequent records are the time and associated current magnitudes (cm/sec).*

### 4.5 Description of output data files from the NearField module

Examples of content of the different output files are given in the end of the section.

scenario.**DBS**
Summary of results from plume simulation.

| Parameter | Unit | Explanation |
|---|---|---|
| HOUR | hours | Start time of individual plume simulations with reference to times in the current data record |
| H | m | Depth corresponding to maximum plume rise (Depth of Trapping, DOT) |
| X | m | East displacement of plume at DOT |
| Y | m | North displacement of plume at DOT |
| R | m | Plume radius at DOT |
| U | cm/s | Horizontal component of plume velocity at DOT |
| W | cm/s | Vertical component of plume velocity at DOT |
| Str | $m^2/s$ | Source strength, measure of surface spreading rate for surfacing plumes |
| D95 | mm | 95% maximum droplet size formed at exit |
| Time | seconds | Rise time to DOT |
| ppm | 1.e-6 | Oil concentration in plume at DOT |
| %G | % | Mass fraction of gas reaming as gas bubbles at DOT |
| %D | % | Mass fraction of gas dissolved in plume at DOT |
| %H | % | Mass fraction of gas in hydrate at DOT |

scenario.**DBP**
Data on individual plume trajectories.
Repeated for each plume, separated by one line.

| Parameter | Unit | Explanation |
|---|---|---|
| First column | hours | First row in sequence: Start time in hours of individual plume simulations with reference to times in the current data record. |
| | seconds | Subsequent rows: Rise time in seconds from start of plume trajectory. Note: Time intervals determined in user interface. |
| X | m | East displacement of plume centerline |
| Y | m | North displacement of plume centerline |
| H | m | Depth of plume centerline |
| R | m | Plume radius |
| U | cm/s | Horizontal component of plume velocity |
| W | cm/s | Vertical component of plume velocity |
| T | $^oC$ | Temperature in plume |
| S | 1.e-3 | Salinity in plume |
| ppm | 1.e-6 | Oil concentration in plume |
| Gas | % | Mass fraction of gas remaining as gas bubbles |
| Diss | % | Mass fraction of gas dissolved in plume |
| Hydrate | % | Mass fraction of gas in hydrate |

***scenario*.COS**
Summary data for surface slicks

| Parameter | Unit | Explanation |
|---|---|---|
| Time | hours | Time from start of release |
| Qrel | $m^3$ | Released oil volume |
| Qsurf | $m^3$ | Surfaced oil volume |
| % | % | Volume fraction of oil surfaced |
| Microns | 1.e-6 m | Average thickness of surface slick |

***scenario*.COT**
Distribution of film thickness in surface slick at different times after release (snapshots)
First snapshot at end time of release. Sequence repeated for each snapshot, separated by blank line.

| Parameter | Unit | Explanation |
|---|---|---|
| First row in sequence | hours | Text including time of the snapshot in hours from start of release |
| Second row in sequence | | 1 – 4$^{th}$ column: Column headers in sequence |
| | | 5$^{th}$ column: Time from start, hours |
| | | 6$^{th}$ column: Number of rows in sequence |
| | | 7$^{th}$ column: Average surface film thickness, microns |
| NCL | m | Cell number |
| km_East | m | Distance of cell east of discharge point |
| km_North | m | Distance of cell north of discharge point |
| microns | 1.e-6 m | Oil film thickness in cell |

**Example of file *scenario*.DBS: Summary of results from plume simulation**

| HOUR | H | X | Y | R | U | W | Str | D95 | Time | ppm | %G | %D | %H |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 120.0 | 10.7 | 46.7 | -27.6 | 34.7 | 11.1 | 35.0 | 268.7 | 3.6 | 583.0 | 38.9 | 55.0 | 22.1 | 0.0 |
| 120.5 | 6.5 | 45.4 | -22.6 | 29.6 | 12.7 | 60.1 | 387.7 | 3.1 | 475.0 | 18.5 | 72.2 | 20.6 | 0.0 |
| 121.0 | 8.6 | 56.7 | -19.7 | 31.5 | 15.6 | 55.1 | 381.9 | 3.4 | 475.0 | 10.7 | 66.7 | 20.3 | 0.0 |
| 121.5 | 17.0 | 74.4 | -14.7 | 38.8 | 18.2 | 37.8 | 333.1 | 3.7 | 502.0 | 7.6 | 55.5 | 20.1 | 0.0 |
| 122.0 | 35.3 | 98.3 | -4.6 | 48.2 | 21.8 | 20.4 | 256.5 | 4.1 | 541.0 | 5.9 | 39.0 | 19.7 | 0.0 |
| 122.5 | 45.7 | 110.9 | 10.8 | 51.7 | 24.0 | 13.0 | 210.3 | 4.5 | 571.0 | 4.8 | 31.6 | 19.9 | 0.0 |
| 123.0 | 53.9 | 133.9 | 32.1 | 54.2 | 25.4 | 2.6 | 95.7 | 4.9 | 650.0 | 4.0 | 19.2 | 20.0 | 0.0 |
| 123.5 | 93.7 | 682.2 | 375.2 | 95.5 | 27.4 | 5.4 | 253.9 | 5.4 | 3023.0 | 1.0 | 0.0 | 24.2 | 0.0 |
| 124.0 | 74.3 | 140.2 | 71.9 | 50.6 | 27.7 | 0.0 | 0.0 | 6.0 | 694.0 | 3.2 | 11.6 | 19.0 | 0.0 |
| 124.5 | 81.4 | 137.3 | 92.8 | 48.8 | 28.7 | 0.0 | 0.0 | 6.6 | 712.0 | 3.0 | 9.1 | 18.4 | 0.0 |
| 125.0 | 91.9 | 132.4 | 117.6 | 47.0 | 28.4 | 0.0 | 0.0 | 7.3 | 758.0 | 2.9 | 5.5 | 16.7 | 0.0 |
| 125.5 | 100.1 | 125.2 | 135.6 | 46.1 | 27.7 | 0.0 | 0.0 | 8.0 | 798.0 | 2.7 | 3.8 | 16.1 | 0.0 |
| 126.0 | 106.3 | 105.0 | 149.5 | 44.4 | 27.9 | 0.0 | 0.0 | 8.9 | 803.0 | 2.5 | 3.1 | 15.3 | 0.0 |
| 126.5 | 113.7 | 83.9 | 156.6 | 42.8 | 26.4 | 0.0 | 0.0 | 9.9 | 815.0 | 2.5 | 2.2 | 13.8 | 0.0 |
| 127.0 | 123.8 | 60.1 | 160.3 | 41.9 | 24.1 | 0.0 | 0.0 | 11.3 | 845.0 | 2.5 | 1.4 | 12.0 | 0.0 |
| 127.5 | 216.1 | 9.9 | 366.3 | 33.7 | 18.2 | 0.0 | 0.0 | 11.7 | 1913.0 | 1.5 | 0.0 | 3.7 | 0.0 |
| 128.0 | 267.0 | -235.0 | 613.2 | 11.1 | 20.8 | 0.0 | 0.0 | 11.7 | 3223.0 | 2.2 | 0.0 | 0.2 | 0.0 |
| 128.5 | 276.0 | -296.1 | 482.4 | 7.7 | 18.4 | 0.0 | 0.0 | 11.7 | 3121.0 | 1.8 | 0.0 | 0.0 | 0.0 |

**Example of *scenario*.DBP: Data on individual plume trajectories**

Note: Only first two sequences shown.

| 120 | X | Y | H | R | U | W | T | S | ppm | Gas | Diss | Hydr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.1 | -0.1 | 296.8 | 0.6 | 11.2 | 99.7 | 5.5 | 35.0 | 49450.8 | 100.0 | 0.0 | 0.0 |
| 60 | 2.9 | -4.9 | 251.3 | 6.1 | 7.0 | 63.4 | 5.4 | 35.0 | 732.2 | 96.5 | 3.5 | 0.0 |
| 120 | 5.1 | -8.1 | 216.2 | 10.1 | 6.8 | 55.1 | 5.5 | 35.0 | 301.8 | 93.4 | 6.6 | 0.0 |
| 180 | 7.8 | -12.0 | 184.3 | 13.5 | 9.0 | 51.9 | 5.5 | 35.0 | 179.6 | 90.4 | 9.5 | 0.0 |
| 240 | 11.5 | -16.8 | 153.9 | 16.7 | 10.9 | 49.4 | 5.5 | 35.0 | 122.1 | 85.4 | 12.2 | 0.0 |
| 300 | 16.5 | -21.0 | 124.7 | 19.7 | 10.6 | 47.8 | 5.6 | 35.0 | 91.1 | 79.3 | 14.6 | 0.0 |
| 360 | 22.1 | -23.9 | 96.6 | 22.5 | 10.6 | 46.0 | 5.7 | 35.0 | 71.8 | 73.8 | 16.7 | 0.0 |
| 420 | 28.3 | -25.8 | 70.1 | 26.6 | 11.1 | 41.6 | 5.9 | 35.0 | 56.8 | 69.3 | 18.6 | 0.0 |
| 480 | 35.1 | -26.8 | 46.8 | 31.0 | 11.5 | 36.6 | 6.1 | 35.0 | 46.7 | 64.4 | 20.2 | 0.0 |
| 540 | 41.9 | -27.3 | 25.5 | 33.6 | 11.3 | 34.6 | 6.3 | 35.0 | 41.9 | 58.6 | 21.4 | 0.0 |

| 120.5 | X | Y | H | R | U | W | T | S | ppm | Gas | Diss | Hydr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.1 | -0.1 | 296.5 | 0.7 | 13.0 | 109.1 | 5.5 | 35.0 | 22301.6 | 100.0 | 0.0 | 0.0 |
| 60 | 4.3 | -5.1 | 245.9 | 6.7 | 8.8 | 70.8 | 5.4 | 35.0 | 308.9 | 96.4 | 3.6 | 0.0 |
| 120 | 8.0 | -8.5 | 206.5 | 11.2 | 8.8 | 62.0 | 5.5 | 35.0 | 126.0 | 93.2 | 6.8 | 0.0 |
| 180 | 12.1 | -12.7 | 170.4 | 14.9 | 10.8 | 59.0 | 5.5 | 35.0 | 74.2 | 90.2 | 9.8 | 0.0 |
| 240 | 17.4 | -17.1 | 135.5 | 18.4 | 11.7 | 57.3 | 5.6 | 35.0 | 50.4 | 86.5 | 12.5 | 0.0 |
| 300 | 23.8 | -19.9 | 101.6 | 21.7 | 11.7 | 55.9 | 5.7 | 35.0 | 36.8 | 82.6 | 15.1 | 0.0 |
| 360 | 30.8 | -21.6 | 68.5 | 25.2 | 12.4 | 54.0 | 5.9 | 35.0 | 28.3 | 78.8 | 17.3 | 0.0 |
| 420 | 38.4 | -22.4 | 36.7 | 28.4 | 12.8 | 53.0 | 6.2 | 35.0 | 22.6 | 74.8 | 19.2 | 0.0 |

**Example of *scenario*.COS: Summary data from surface slick calculations**

Release duration, hrs: 9.0

| Time | Qrel | Qsurf | % | Microns |
|---|---|---|---|---|
| 9 | 429.8 | 429.1 | 99.9 | 39.1 |
| 10 | 429.8 | 429.7 | 100.0 | 30.3 |
| 11 | 429.8 | 429.8 | 100.0 | 27.3 |
| 12 | 429.8 | 429.8 | 100.0 | 25.1 |
| 13 | 429.8 | 429.8 | 100.0 | 22.9 |
| 14 | 429.8 | 429.8 | 100.0 | 20.0 |

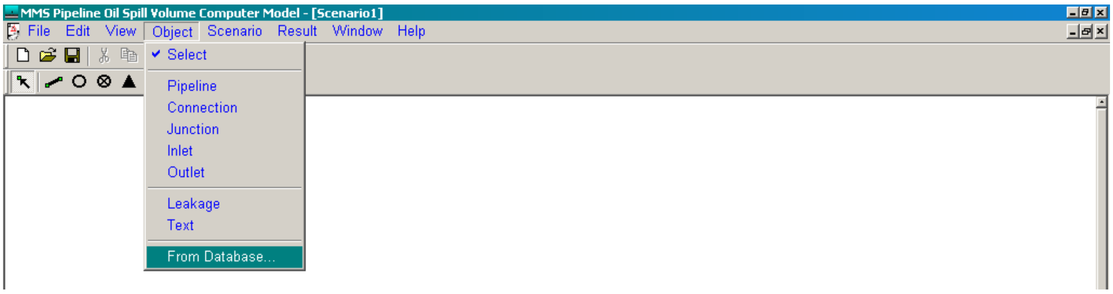
**Example of *scenario*.COT : Distribution of film thickness in surface slicks.**
Note: Only parts of first sequence shown.

Concentrations_at_time,_hours: 9.0

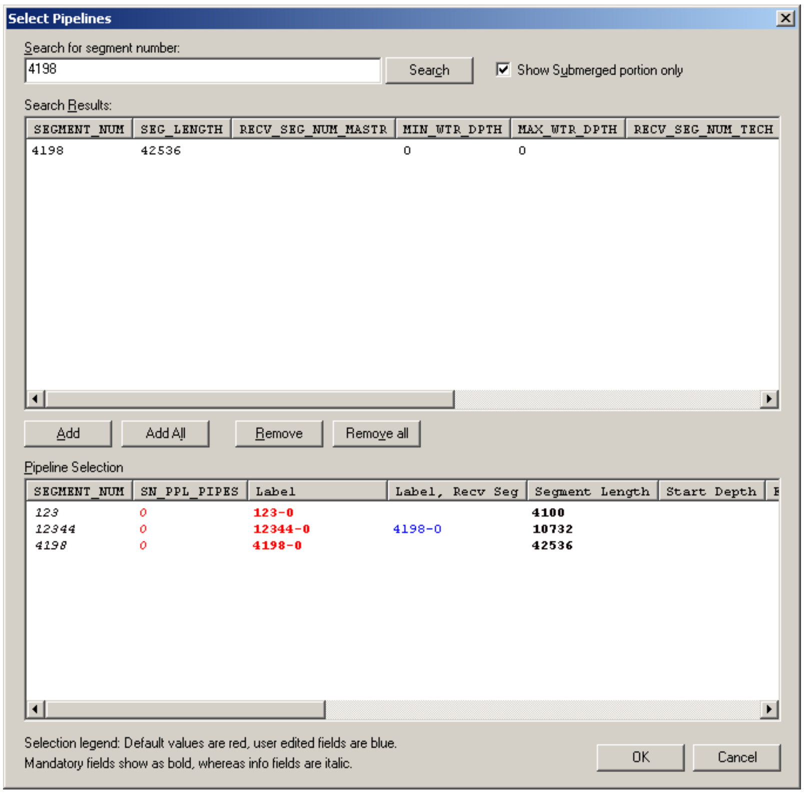
| NCL | km_East | km_North | microns | 9 | 482 | 39.1 |
|---|---|---|---|---|---|---|
| 1 | -0.188 | 0.747 | 2.680 | | | |
| 2 | -0.037 | 0.747 | 36.447 | | | |
| 3 | 0.114 | 0.747 | 5.310 | | | |
| 4 | -0.188 | 0.898 | 2.168 | | | |
| 5 | -0.037 | 0.898 | 38.307 | | | |
| 6 | 0.114 | 0.898 | 4.877 | | | |
| 7 | 0.265 | 0.898 | 0.105 | | | |
| 8 | -0.188 | 1.049 | 0.450 | | | |
| 9 | -0.037 | 1.049 | 0.829 | | | |
| 10 | 0.114 | 1.049 | 0.886 | | | |
| 11 | 0.265 | 1.049 | 0.574 | | | |
| 12 | 0.416 | 1.049 | 0.120 | | | |

# 5 Connection to the MMS Pipeline Information Database

The POSVCM allows the user to draw data directly from the MMS Pipeline Information Database. To access the database, go to the menu item Object>From Database.




This brings up the Select Pipelines dialogue window:




By entering the desired pipeline segment numbers in the top dialogue box and clicking Select (or the Enter key on the keyboard), segment numbers with associated data are collected in the upper half of the window (the "Search Results" window). Any or all of these may then be added to the active Scenario using the Add and Add All buttons between the top and bottom windows, or by double-clicking the desired segments. This will add segments to the current selection, shown in the lower half of the window (the "Pipeline Selection" window). Clicking OK closes the window, and places the selected pipeline segments in the active Scenario.

Data retrieved from the database for each pipeline segment include

- ID number,
- Length,
- Diameter and wall thickness (to compute inside diameter),
- Receiving segment number (to identify potential joins).

Other data, such as pipe grade and minimum and maximum water depths, are also retrieved, but are not used in the present version of the model. They are however displayed, in order to aid the user in selecting segments and editing data. For instance, minimum and maximum depth may give a hint to the start and end depth of a segment.

As described in the next chapter, a number of properties must be supplied for each pipeline segment. As far as possible, these are taken from the information in the database. Some data are however not available from the database, in which case the same default values as used elsewhere in the model are supplied.

Font and color coding is used in the selection window to indicate field status. Some fields are mandatory, meaning that they must be supplied for the model to be able to run correctly. These are shown in bold. Optional fields are in standard font, whereas info fields containing data that is not used in the model show in italics. The text color indicates the data source. System default is used for data from the database, red is used for data supplied by the database module (e.g. default values), and user edited data is written in blue.

The user can edit field values by double-clicking the corresponding field. It is advised that the user consider editing data fields where default values are used for parameters central to the model, such as start and end depth.

Each selected pipeline segment is given a unique label. Labels are generated as [SEGMENT_NUM]-[SN_PPL_PIPES], but can be changed by the user after selection.

Pipeline segments can be connected by entering labels in the “Label, Recv Seg” field. This will create a joint between the two segments in the scenario. If either end depth of sending segment or start depth of receiving segment is specified, this will be used as the depth of their common joint. If both depths are given, depth of sender is used.

In some cases the database contains the segment number of the receiving segment. The user can then right-click the segment in the “Search Results” window and select “Search for receiving segment” from the drop-down menu to find the receiving segment. Note that the two segments are not automatically connected, this must be done by double-clicking the “Label, Recv Seg” field of the sending segment and entering the receiving segment’s label.

All units are as in the main program when the user has selected to display “English (US)” units.

## 6 Test Cases

Six documented pipeline spill events have been used to test the software. The background documentation was supplied by MMS, primarily from internal reports. Schematics and input data for these cases are supplied in each section.

Table 3 summarizes results of the 6 oil release events used to test the POSVCM. Some important input data were lacking in most cases. For example, all lacked documentation of the gas-oil ratio. Only Case 1 gives the fractional water cut in the pipeline, and the flow rate is lacking in 4 out of the 6 reports. These are all critical parameters for producing a good estimate of released volumes. Each case is discussed briefly below.

### 6.1 Irene Pipeline Leak, September 28, 1987

This leak was due to a crack in a 20-inch pipeline connecting an offshore platform to a land-based oil handling facility. The documentation included most of the data necessary for the model. However, the model estimate is about 4 times higher than the maximum estimate in the report of 163 bbl. A pigging operation was underway when the leak occurred, and the maximum estimate in the report was based on the assumption that all the oil and water in the line between the pig and the break at the time of the first platform shut-in was released. This analysis assumes that no oil from the pipeline on the other side of the break was released, whereas in the model, gas expansion results in loss of oil from both sides of the break.

**Fluid properties:**

| | | |
|---|---|---|
| Gas density: | lb/scf | 0.06 |
| Oil density | ppg | 6.7 |
| Gas-Oil Ratio | scf/stb | 30 |
| Percent water in fluid | % | 84 |

**Flow inlet properties:**

| | | |
|---|---|---|
| Depth | ft | 40 |
| Total liquid flow rate | stbd | 66719.8 |
| Fluid temperature | °F | 120 |
| Closing time | min | 25 |

**Pipeline 1: "Riser"**

| | | |
|---|---|---|
| Length | ft | 284.01 |
| Inside diameter | in | 18.622 |
| Roughness coefficient: | ft | 0.000164042 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 50 |

**Pipeline 2: "Torch 20-inch line"**

| | | |
|---|---|---|
| Length | ft | 30600 |
| Inside diameter | in | 18.6 |
| Roughness coefficient: | ft | 0.00016 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1768 |
| Ambient temperature | °F | 50 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 244 |

**Outlet:**

| | | |
|---|---|---|
| Depth | ft | 120 |

| | | |
|---|---|---|
| Fluid pressure | psi | 680 |
| Closing time | min | 0 |

**Leak properties:**

| | | |
|---|---|---|
| Distance from upstream endpoint | ft | 30578 |
| Nominal diameter | in | 18.6 |
| Water depth. | ft | 122 |

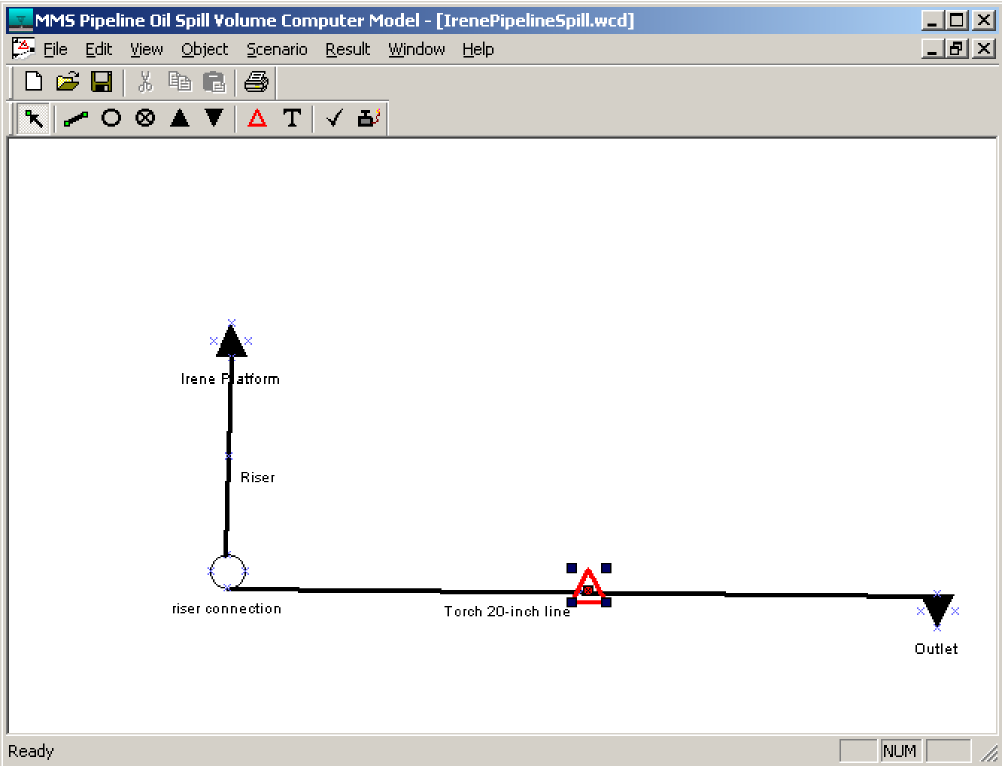



*Figure 6.1 Graphical description of the layout for the Irene Pipeline Spill.*

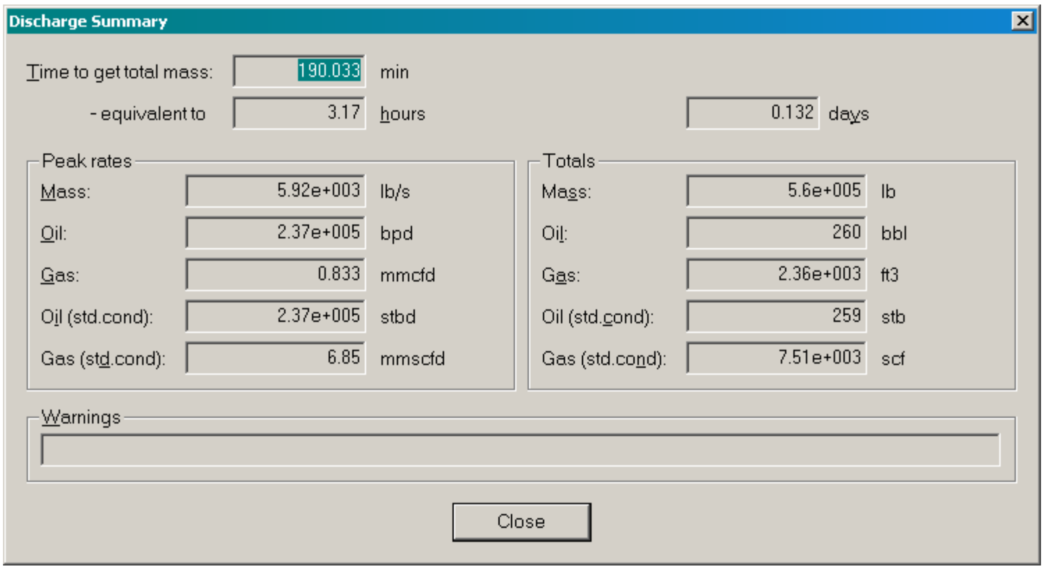



*Figure 6.2 Result window for the Irene Pipeline Spill.*

### 6.2 Chevron South Pass Block 38, September 29, 1998

Hurricane George (September 1998) caused an underwater mudslide and complete separation of a 10" pipeline at a water depth of 110 feet. The pipe was found covered with 20 feet of mud, and mud entered both end of the pipe for a distance of 4 feet on one end and 20 feet on the other. The report for this case is relatively complete, although the gas-oil ratio and oil properties are lacking. The network is relatively complex. The model estimate of about 6000 bbl lost is somewhat under the reported estimates at around 8000 bbl. The pipeline system was put through a relatively complex series of tests to determine whether there was a leak, and later to locate the leak. This complexity is not accounted for in the model, and probably explains the lower estimated discharge estimated by the model.

**Fluid properties:**

| | | |
|---|---|---|
| Gas density: | lb/scf | 0.062 |
| Oil density | ppg | 6.7 |
| Gas-Oil Ratio | scf/stb | 25 |
| Percent water in fluid | % | 80 |

**Flow inlet: Cusa Platforms MC 49A,B,C**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 6289.81 |
| Fluid temperature | °F | 140 |
| Closing time | min | 60 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 1312 |
| Inside diameter | in | 9.84 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 393.70 |

**Pipeline: "Pipe 10" Line to Cusa"**

| | | |
|---|---|---|
| Length | ft | 39370 |
| Inside diameter | in | 9.842 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 68 |

**Flow inlet: Taylor Platform MC20**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 628.98 |
| Fluid temperature | °F | 140 |
| Closing time | min | 60 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 656 |
| Inside diameter | in | 7.87 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 393.70 |

**Pipeline: "8" line to Taylor"**

| | | |
|---|---|---|
| Length | ft | 53234 |
| Inside diameter | in | 7.87 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 41 |

**Pipe junction:**

| | | |
|---|---|---|
| Depth | ft | 393.7 |

**Pipeline: "Pipe 10" Line upstream from BP"**

| | | |
|---|---|---|
| Length | ft | 3280 |
| Inside diameter | in | 9.84 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 68 |

**Flow inlet: BP Platform MC109**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 10296.4 |
| Fluid temperature | °F | 140 |
| Closing time | min | 60 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 656 |
| Inside diameter | in | 9.84 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 393.70 |

**Pipeline: "10" line to BP"**

| | | |
|---|---|---|
| Length | ft | 38753.3 |
| Inside diameter | in | 9.84 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 68 |

**Pipe junction:**

| | | |
|---|---|---|
| Depth | ft | 393.7 |

**Pipeline: " Pipe 10" Line Upstream from BP "**

| | | |
|---|---|---|
| Length | ft | 65616.8 |
| Inside diameter | in | 9.84 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 68 |

**Flow inlet : OXY Platform SP 45**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 188.69 |
| Fluid temperature | °F | 140 |
| Closing time | min | 60 |

**Pipeline: " 4" line to OXY "**

| | | |
|---|---|---|
| Length | ft | 4717.85 |
| Inside diameter | in | 3.93 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 68 |

**Pipe junction:**

| | | |
|---|---|---|
| Depth | ft | 131.23 |

**Pipeline: " Pipe 10" Line to Outlet"**

| | | |
|---|---|---|
| Length | ft | 36417.3 |
| Inside diameter | in | 9.84 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 68 |

**Outlet: " on shore"**

| | | |
|---|---|---|
| Depth | ft | -50 |
| Fluid pressure | psi | 36.706 |
| Closing time | min | 0 |

**Leak properties:**

| | | |
|---|---|---|
| Distance from upstream endpoint | ft | 16404.2 |
| Nominal diameter | in | 9.84 |
| Water depth. | ft | 131.23 |

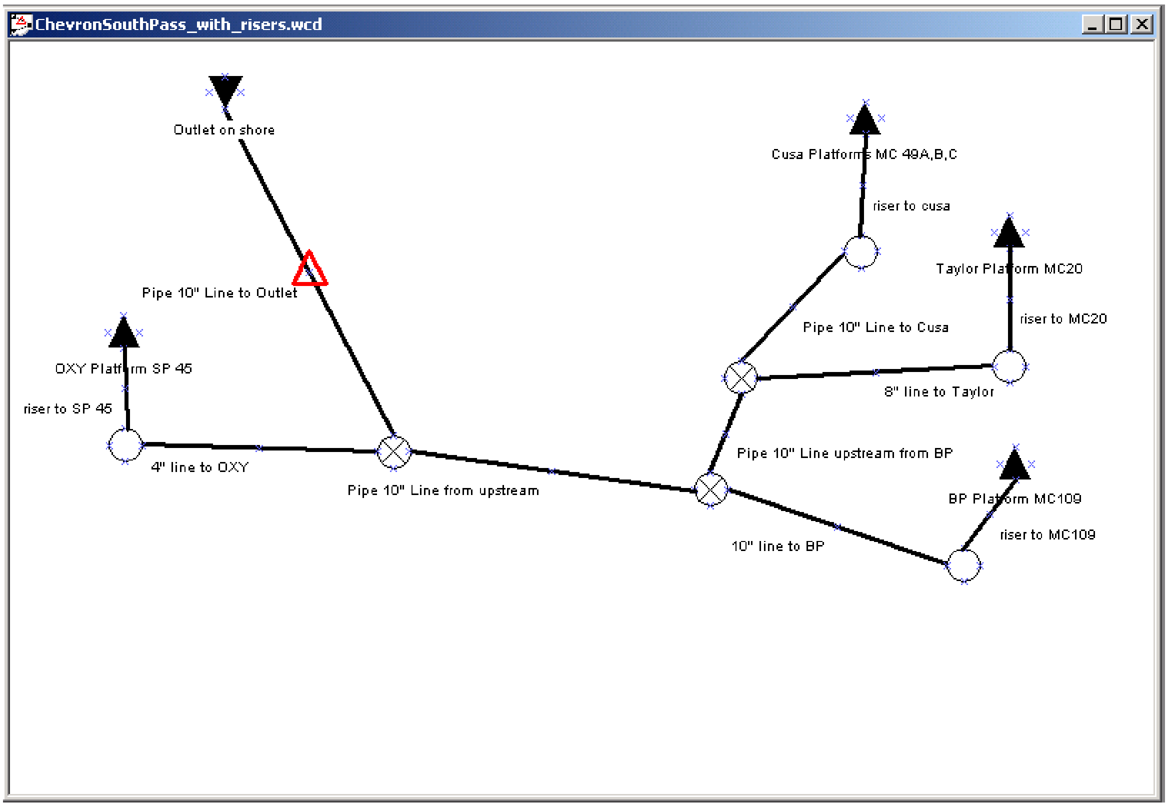



*Figure 6.3 Graphical description of the Chevron South Pass Spill.*

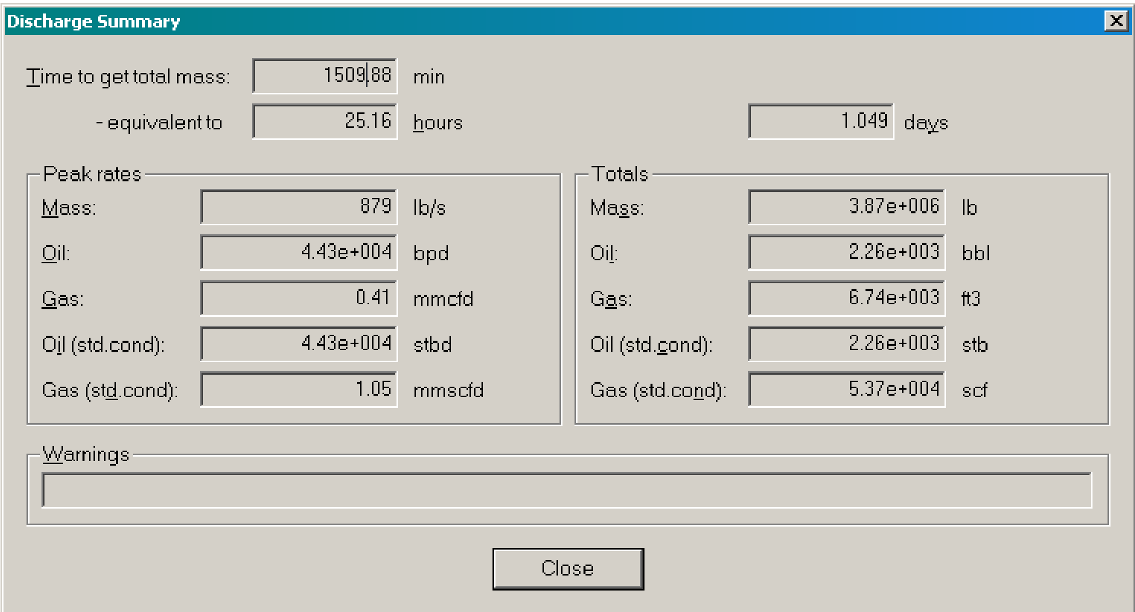



*Figure 6.4 Result window for the Chevron South Pass Spill*

## 6.3 Exxon Eugene Island Block 314, May 6, 1990

In this case a 1-inch valve was broken off a pipeline, probably due to trawling activity in the area. The model estimate of 12,300 bbl released is near the reported maximum estimate of 13,600 bbl, but since the flow rates were roughly estimated from monthly throughput rates in the report, this may be simply coincidence.

**Fluid properties:**

| | | |
|---|---|---|
| Gas density: | lb/scf | 0.062 |
| Oil density | ppg | 6.7 |
| Gas-Oil Ratio | scf/stb | 25 |
| Percent water in fluid | % | 0 |

**Flow inlet properties "Platform B":**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 6289.81 |
| Fluid temperature | °F | 68 |
| Closing time | min | 30 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 328.084 |
| Inside diameter | in | 7.87 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 164.042 |

**Pipeline: "8 5/8 inch (out of service)"**

| | | |
|---|---|---|
| Length | ft | 5000 |
| Inside diameter | in | 7.87 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 41 |

**Flow inlet: "upstream sources"**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 12139.3 |
| Fluid temperature | °F | 68 |
| Closing time | min | 1440 |

**Pipeline: "EIPS 20-inch line"**

| | | |
|---|---|---|
| Length | ft | 328.084 |
| Inside diameter | in | 19.685 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 41 |

**Pipe junction "8 5/8 to 20" junction":**

| | | |
|---|---|---|
| Depth | ft | 164.042 |

**Pipeline: "EIPS 20-inch line #2"**

| | | |
|---|---|---|
| Length | ft | 3280 |
| Inside diameter | in | 19.685 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Outlet: " towards shore"**

| | | |
|---|---|---|
| Depth | ft | 164.04 |
| Fluid pressure | psi | 580.15 |
| Closing time | min | 1440 |

**Leak properties:**

| | | |
|---|---|---|
| Distance from upstream endpoint | ft | 4970.47 |
| Nominal diameter | in | 1 |
| Water depth. | ft | 164.04 |
| Back pressure | psi | 87.946 |

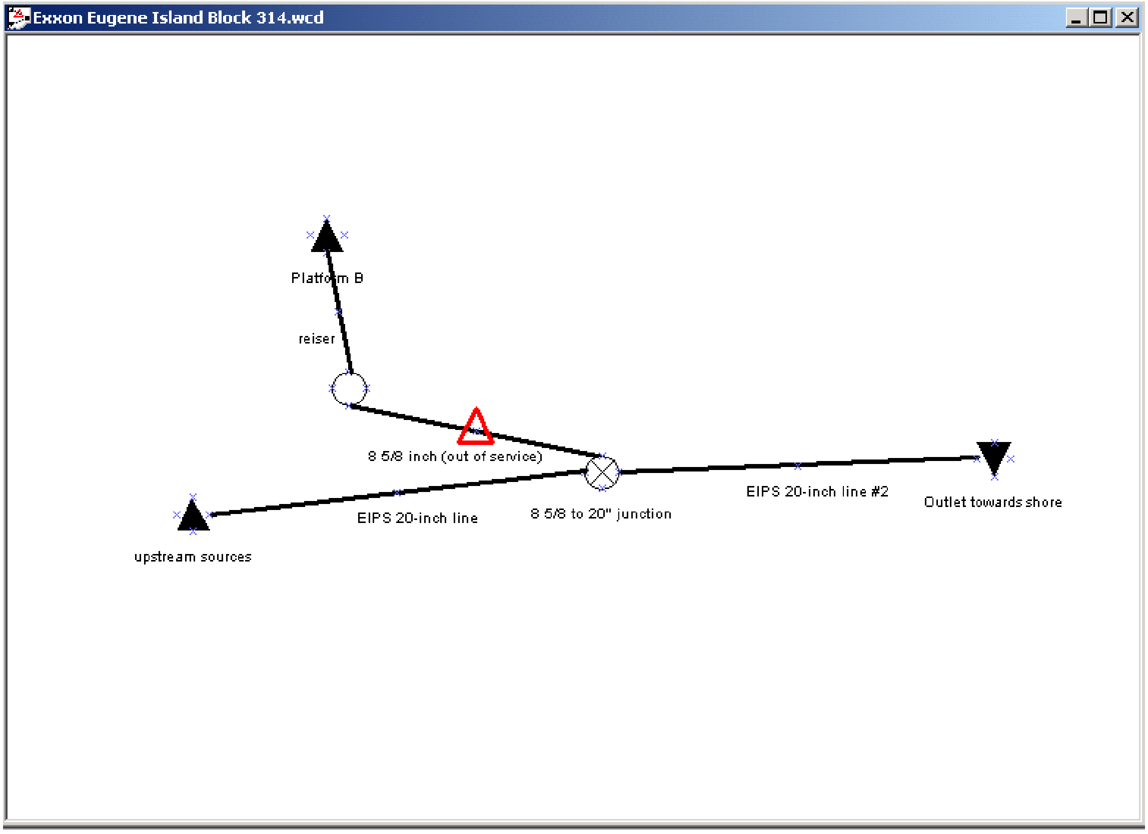



*Figure 6.5 Graphical description of the Exxon Eugene Island Block 314, May 6, 1990.*

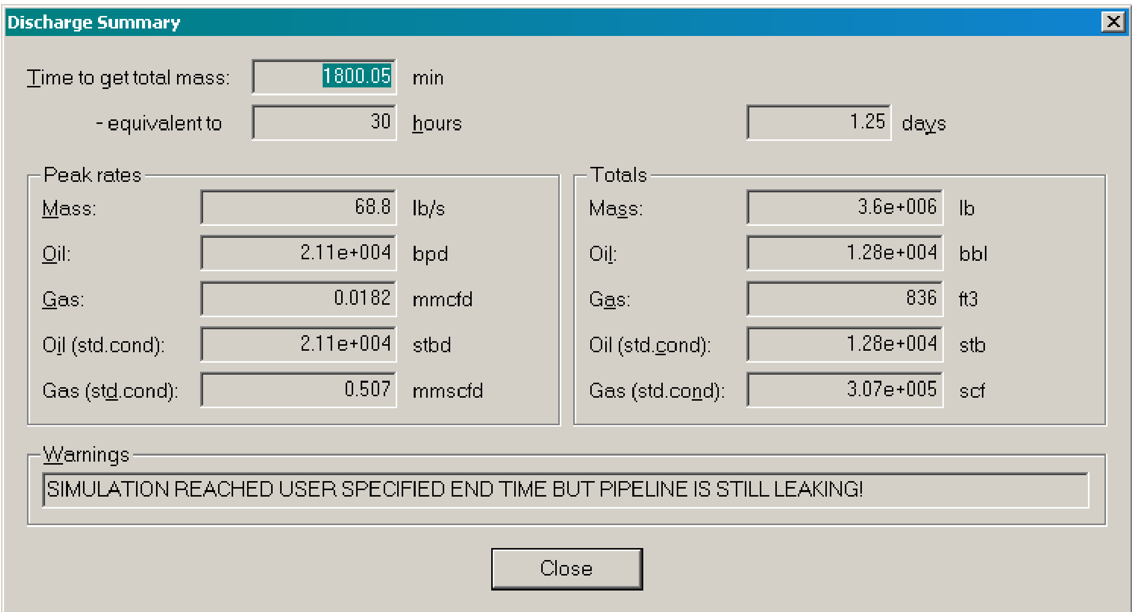



*Figure 6.6 Output window of the Exxon Eugene Island Block 314, May 6, 1990.*

### 6.4 Shell Hobbit Pipeline Block 281, January 24, 1990

This is the first of two pipeline spills from this network. Here a 2-inch valve was separated from the 4-inch pipeline, again perhaps due to trawling activity. Flow rates and GOR are missing, so this calculation must be considered unreliable. The 31,500 bbl estimate from the model is within the range of estimates given in the report, but with a minimum of 9570 and a maximum of 159,000 bbl, the target area is reasonably broad.

**Fluid properties:**

| | | |
|---|---|---|
| Gas density: | lb/scf | 0.062 |
| Oil density | ppg | 6.7 |
| Gas-Oil Ratio | scf/stb | 25 |
| Percent water in fluid | % | 0 |

**Flow inlet properties "Ship Shoal Block 259 Platform A":**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 0 |
| Fluid temperature | °F | 68 |
| Closing time | min | 1440 |

**Pipeline: "Hobbit 4" line"**

| | | |
|---|---|---|
| Length | ft | 31988 |
| Inside diameter | in | 19.6 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 41 |

**Flow inlet: "upstream platforms"**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 6289.8 |
| Fluid temperature | °F | 68 |
| Closing time | min | 1440 |

**Pipeline: "12" Cougar lione #2"**

| | | |
|---|---|---|
| Length | ft | 32808.4 |
| Inside diameter | in | 19.6 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Pipe junction:**

| | | |
|---|---|---|
| Depth | ft | 203.4 |

**Pipeline: "12" Cougar line upstream"**

| | | |
|---|---|---|
| Length | ft | 32808.4 |
| Inside diameter | in | 19.685 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Flow inlet: "Ship Shoal block 241 A"**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 6289.8 |
| Fluid temperature | °F | 68 |
| Closing time | min | 1440 |

**Pipeline: "12" line to Ship Shoal 208"**

| | | |
|---|---|---|
| Length | ft | 29527.6 |
| Inside diameter | in | 19.68 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Outlet: " Ship Shoal Block 208 Platform F"**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Fluid pressure | psi | 580.15 |
| Closing time | min | |

**Leak properties:**

| | | |
|---|---|---|
| Distance from upstream endpoint | ft | 31981.6 |
| Nominal diameter | in | 1.968 |
| Water depth. | ft | 203 |
| Back pressure | psi | 105.5 |

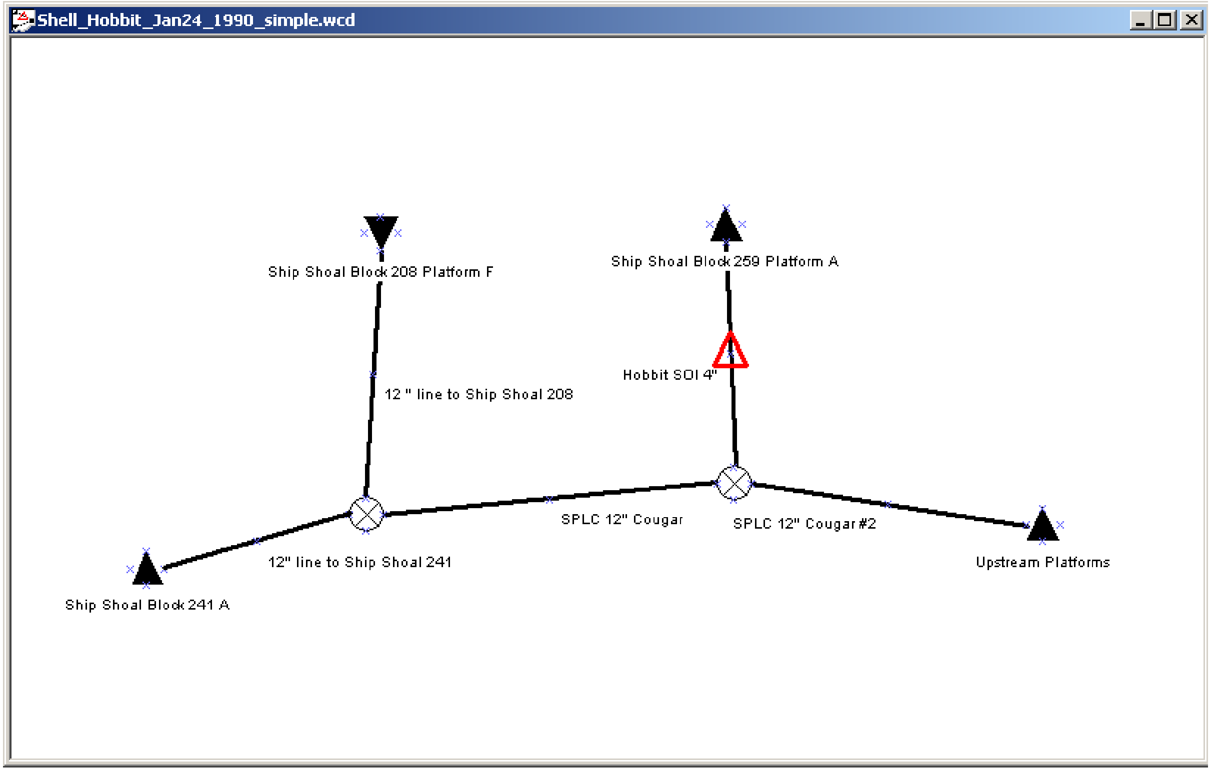



*Figure 6.7 Graphical description of the Shell Hobbit Pipeline Block 281, January 24, 1990.*

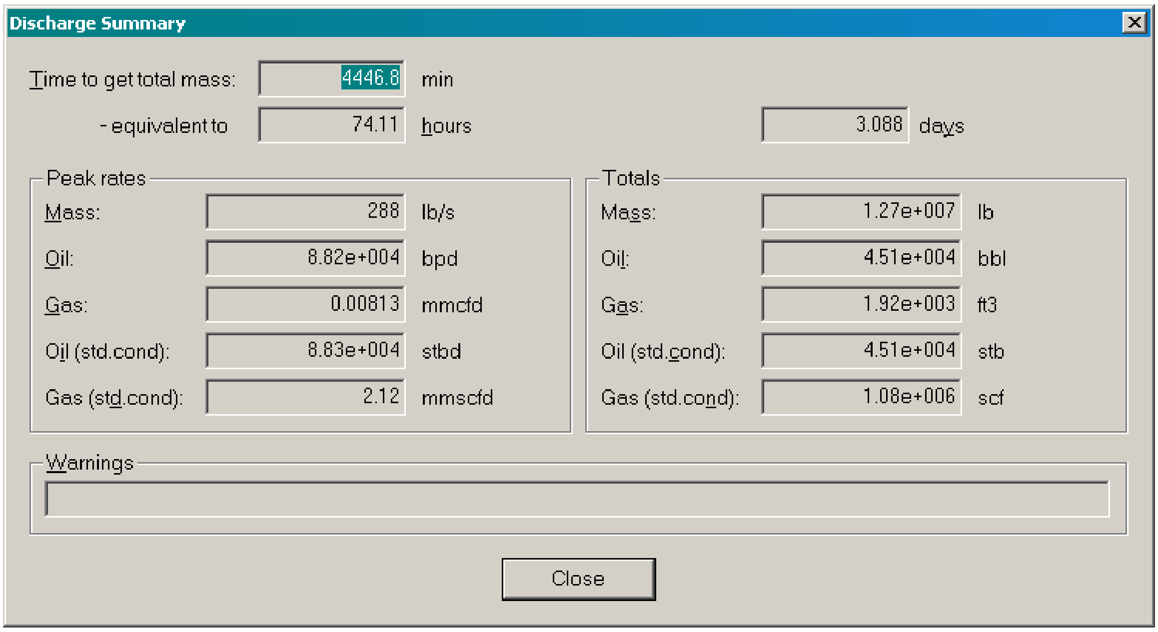



*Figure 6.8 Output window of the Shell Hobbit Pipeline Block 281, January 24, 1990.*

### 6.5 Shell Hobbit Pipeline Block 281, November 16, 1994

This occurrence, at the same location as that for the previous case, was also associated with fishing activity in the area. The estimated release of 12800 bbl far exceeds the reported estimate of 4500 bbl. This appears to be because the reported estimate is based on metering from the platform delivering oil to the main line, whereas the model analysis includes oil from the main line leaking via the break in the tributary line from the platform.

**Fluid properties:**

| | | |
|---|---|---|
| Gas density: | lb/scf | 0.062 |
| Oil density | ppg | 6.7 |
| Gas-Oil Ratio | scf/stb | 25 |
| Percent water in fluid | % | 0 |

**Flow inlet properties "Ship Shoal Block 259 Platform A":**

| | | |
|---|---|---|
| Depth | ft | -80 |
| Total liquid flow rate | stbd | 754.99 |
| Fluid temperature | °F | 120 |
| Closing time | min | 8640 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 294 |
| Inside diameter | in | 4 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 65 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 213 |

**Pipeline: "Hobbit 4" line"**

| | | |
|---|---|---|
| Length | ft | 32000 |
| Inside diameter | in | 4 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 41 |

**Flow inlet: "upstream platforms"**

| | | |
|---|---|---|
| Depth | ft | -80 |
| Total liquid flow rate | stbd | 629 |
| Fluid temperature | °F | 120 |
| Closing time | min | 8640 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 294 |
| Inside diameter | in | 12 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 65 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 213 |

**Pipeline: "12" Cougar lione #2"**

| | | |
|---|---|---|
| Length | ft | 32808.4 |
| Inside diameter | in | 12 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 65 |

**Pipe junction:**

| | | |
|---|---|---|
| Depth | ft | 213 |

**Pipeline: "12" Cougar line upstream"**

| | | |
|---|---|---|
| Length | ft | 32808.4 |
| Inside diameter | in | 19.685 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 65 |

**Flow inlet: "Ship Shoal block 241 A"**

| | | |
|---|---|---|
| Depth | ft | -80 |
| Total liquid flow rate | stbd | 629 |
| Fluid temperature | °F | 120 |
| Closing time | min | 8640 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 294 |
| Inside diameter | in | 12 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 65 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 213 |

**Pipeline: "12" line to Ship Shoal 208"**

| | | |
|---|---|---|
| Length | ft | 29527.6 |
| Inside diameter | in | 12 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Pipeline: "riser"**

| | | |
|---|---|---|
| Length | ft | 294 |
| Inside diameter | in | 12 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 65 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 213 |

**Outlet: " Ship Shoal Block 208 Platform F"**

| | | |
|---|---|---|
| Depth | ft | -80 |
| Fluid pressure | psi | 580.15 |
| Closing time | min | |

| Leak properties: | | |
|---|---|---|
| Distance from upstream endpoint | ft | 32000 |
| Nominal diameter | in | 2 |
| Water depth. | ft | 213 |
| Back pressure | psi | 109.80 |

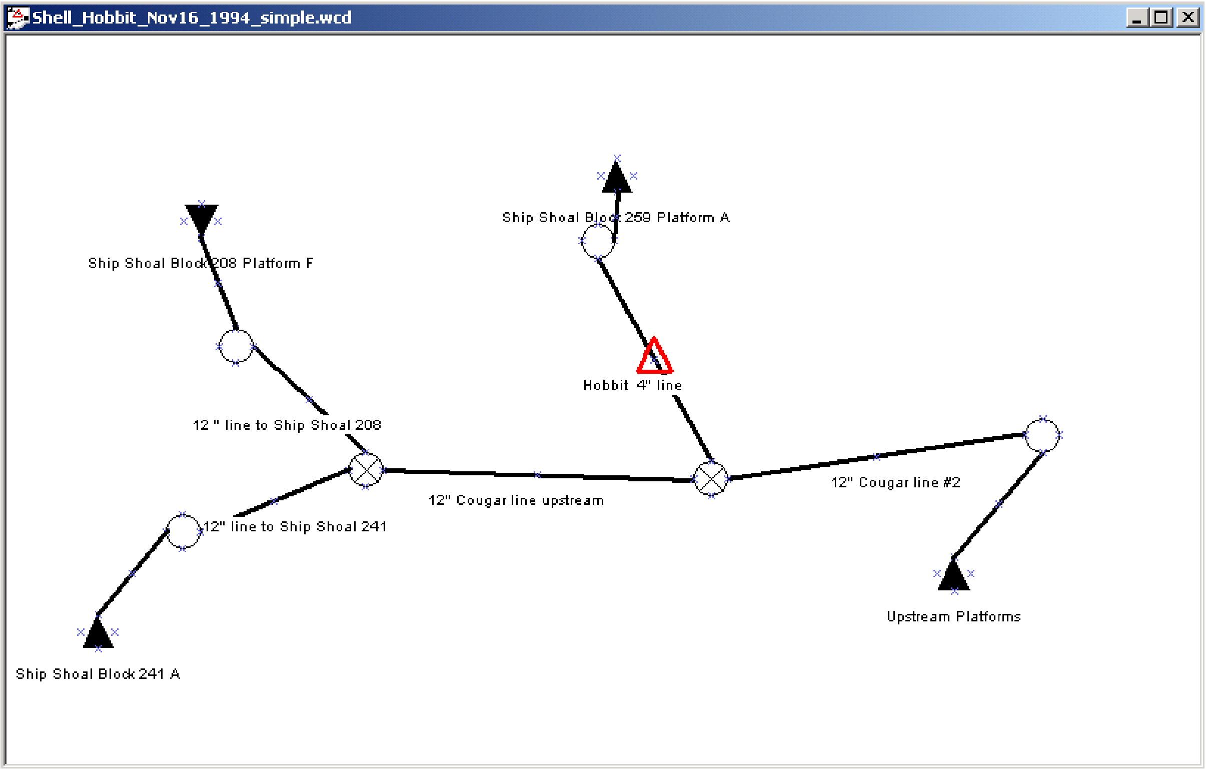



*Figure 6.9 Graphical description of the Shell Hobbit Pipeline Block 281, November 16, 1994.*

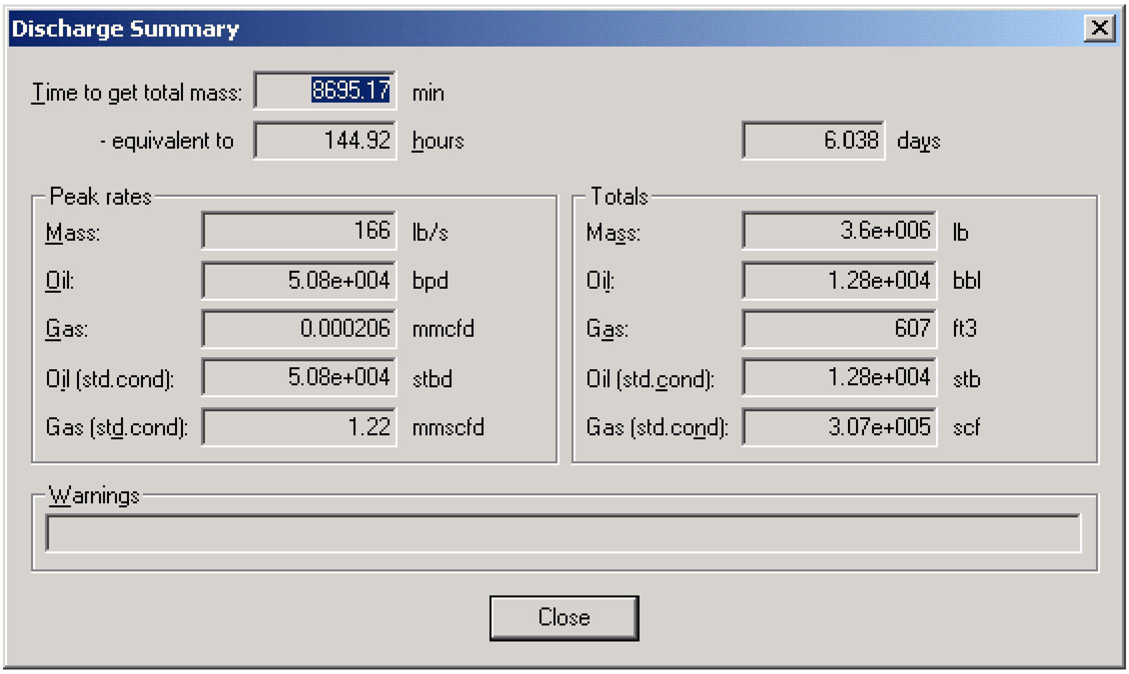



*Figure 6.10 Output window of the Shell Hobbit Pipeline Block 281, November 16, 1994.*

## 6.6 Shell South Pass Block 65, December 30, 1986

In this case oil is transferred from Platform A to Platform B. The model release estimate of 16,500 bbl is less than the reported potential maximum of 23,000 – 29,000 bbl, based on pipeline receipts and deliveries and an analytical leak rate model. Key input parameters for the model analysis are lacking in the report, including GOR, and actual flow rates just prior to the event.

**Fluid properties:**

| | | |
|---|---|---|
| Gas density: | lb/scf | 0.062 |
| Oil density | ppg | 6.7 |
| Gas-Oil Ratio | scf/stb | 280.73 |
| Percent water in fluid | % | 0 |

**Flow inlet properties "Block 65 Platform A":**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Total liquid flow rate | stbd | 10868.8 |
| Fluid temperature | °F | 68 |
| Closing time | min | 4317 |

**Pipeline 1: "riser to Block 65"**

| | | |
|---|---|---|
| Length | ft | 426.50 |
| Inside diameter | in | 7.87 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 301.8 |

**Pipeline 2: "8” line to Block 65"**

| | | |
|---|---|---|
| Length | ft | 2421.2 |
| Inside diameter | in | 7.87 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.176772 |
| Ambient temperature | °F | 41 |

**Pipe connector or junction:**

| | | |
|---|---|---|
| Depth | ft | 301.8 |

**Pipeline 3: "riser to Block 62"**

| | | |
|---|---|---|
| Length | ft | 426.50 |
| Inside diameter | in | 19.685 |
| Roughness coefficient: | ft | 0.000164 |
| Heat transfer coefficient: | BTU/ft$^2$h°F | 0.1767 |
| Ambient temperature | °F | 41 |

**Outlet: " Platform A Block 62"**

| | | |
|---|---|---|
| Depth | ft | -82 |
| Fluid pressure | psi | 2900.75 |
| Closing time | min | 4317 |

**Leak properties:**

| | | |
|---|---|---|
| Distance from upstream endpoint | ft | 2427.8 |
| Nominal diameter | in | 7.87 |
| Water depth. | ft | 301.8 |
| Back pressure | psi | 149.47 |

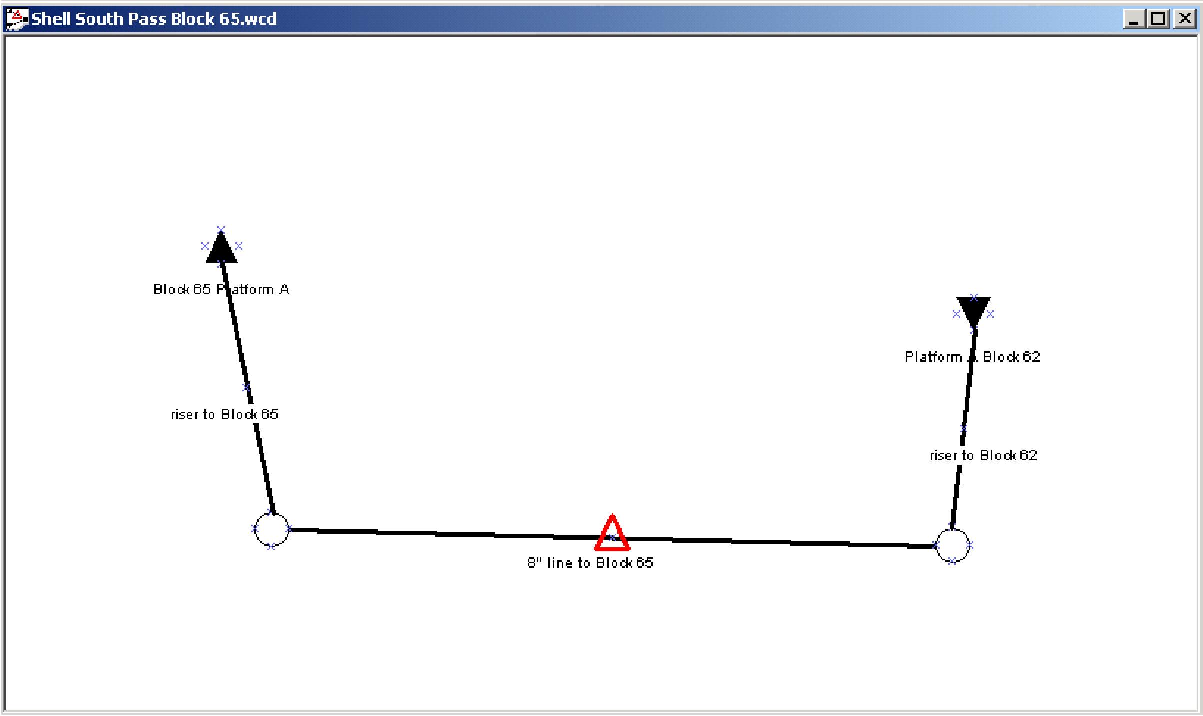



*Figure 6.11 Graphical description of the Shell South Pass Block 65, December 30, 1986.*

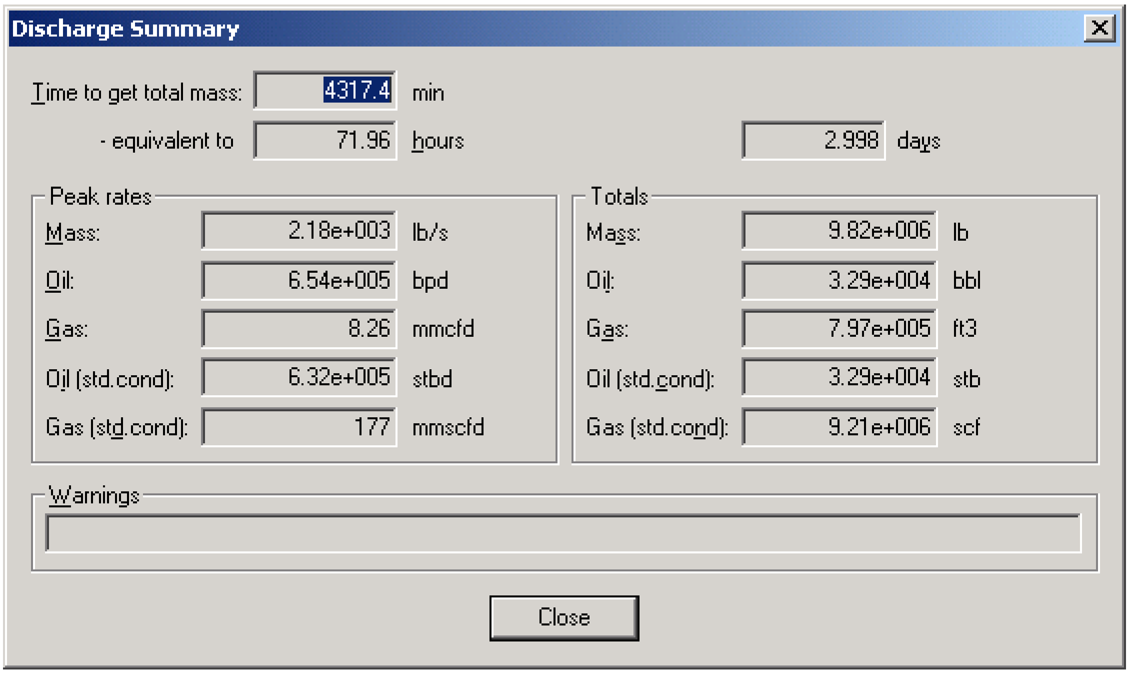



*Figure 6.12 Output window of the Shell South Pass Block 65, December 30, 1986.*

### 6.7 Summary of test scenarios

Table 5.1 summarizes results of the 6 oil release events used to test the POSVCM model. Some important input data was lacking in most cases. For example, all lacked the gas-oil ratio. Only the Irene case gives the fractional water cut in the pipeline, and the flow rate is lacking in 4 out of the 6 reports. These are all critical parameters for producing a good estimate.

Each case is discussed briefly below.

#### 6.7.1 Irene

This report included most of the data necessary for the POSVCM model. However, the models estimate of about 1000 bbl is several times higher than the maximum estimate in the report of 163 bbl. A pigging operation was underway when the leak occurred, and the maximum estimate in the report was based on the assumption that all the oil and water in the line between the pig and the break at the time of the first platform shut-in was released. That analysis assumed that no oil from the pipeline on the other side of the break was released, whereas in the model, gas expansion results in loss of oil from both sides of the break.

Truncating the Torch line shortly after the break location in the model would simulate the presence of the pig in blocking the flow backwards in the line. This can be achieved by entering a length of 30,600 feet for the Torch line (Section 6.1) instead of 63,000 feet. This produces a model estimate of 260 bbl, relatively near the field estimates.

#### 6.7.2 Chevron South Pass

This report is relatively complete, although the gas-oil ratio and oil properties are lacking. The POSVCM estimate of 2260 bbl lost is somewhat under the reported estimates at around 8000 bbl. The reasons for this are not clear at this time.

#### 6.7.3 Exxon Eugene Island

The POSVCM estimate of 12,800 bbl released is near the reported maximum estimate of 13,600 bbl, but since the flow rates were roughly estimated from monthly throughput rates in the report, this may be simply coincidence.

#### 6.7.4 Shell Hobbit 1990 and 1994

Here both flow rates and GOR are missing data, so this calculation must be considered unreliable. The 45,100 bbl estimate from POSVCM is within the range of estimates given in the report, but with a minimum of 9570 and a maximum of 159,000 bbl, the target area is reasonably broad.

The POSVCM estimated release of 12,800 bbl for the 1994 release from the same location far exceeds the reported estimate of 4,500 bbl. This appears to be because the reported estimate is based on metering from the platform delivering oil to the main line, whereas the POSVCM analysis includes oil from the main line leaking via the break in the tributary line from the platform.

### 6.7.5 Shell South Pass Block 65

The POSVCM release estimate of 32,900 bbl somewhat exceeds the reported potential maximum of 23,000 – 29,000 bbl, based on pipeline receipts and deliveries and an analytical leak rate model. Key input parameters for the POSVCM analysis are lacking in the report, including GOR, and actual flow rates just prior to the event.

### 6.7.6 Conclusions

Most of the spill event reports used for testing of the numerical model lack one or more important parameters decisive for a good release estimate. Provision of a standard form to be completed in all such pipeline spill events, would allow the investigator to relatively easily and reliably apply the model. This form should include a sketch of the pipeline layout, with specific parameters being supplied for each pipeline segment, platform, and junction. As time goes on, MMS will thereby build up a relatively strong database for further model testing and improvement.

Testing of the nearfield module has been of limited success based on the available documentation. However, the model has been tested against full-scale field experimental data (Johansen, 2001), and performs well for those situations.

# 7 Suggestions for Future Development

During the course of developing, testing and training, several ideas have been raised for improving the POSVCM. Most promising among these are the following:

1. Integration of bathymetric database: Pipelines on the seafloor generally follow the bathymetric contours. Water depths at the ends of pipeline segments are not available in the TIMS database, but could be drawn automatically from an existing depth database as the scenario is being created. This would give the model the correct slope of each segment, an important factor especially for pipelines containing “dead” oil.
2. Development of a standard form to guide in the collection of data when actual pipeline spills occur: This would allow better testing of the POSVCM in the future.
3. GUI should report total volume of pipeline system. This should be calculated by GUI and be available before simulation. (Can be shown in status bar of each of the scenario windows together with other relevant information).
4. More plot variables. (Accumulated liquid volume out of leak, total liquid content in the pipeline system, etc)
5. Extend the model to better handle stabilized oil. (Current version does a "simple calculation" without time loop).
6. Include plotting capabilities of slick in software (not separate Excel spreadsheet).
7. General: Make the model more robust for all types of cases.

*Table 6.1 Summary results from POSVCM model test scenarios*

| Scenario | POSVCM Estimate (bbl) | Min. Field Estimate (bbl) | Best Field Estimate (bbl) | Max. Field Estimate (bbl) | Comments |
|---|---|---|---|---|---|
| **Irene Pipeline** | 260 | 93 | 163 | 703 | Break occurred during pigging; pig lodged at break; 16% oil in line; assume 122 kg/bbl oil |
| **Chevron South Pass Block 38** | 2260 | | 8200 | 8700 | Assumes 100% oil; GOR 5 |
| **Exxon Engine Island Block 314** | 12800 | 900 | 4560 | 13600 | Depths, flow rates not reported; assumes 100% oil, 3.5 million bbl/month |
| **Shell Hobbit: Jan 24, 1990** | 45100 | 9570 | | 159000 | Assumes 100% oil; only depth at leak site reported (200'); flow rates not given for any lines |
| **Shell Hobbit: Nov 16, 1994** | 12800 | 4420 | | 4530 | Assumes 100% oil; only depth at leak site reported (200'); flow rates not given for any lines |
| **Shell South Pass Block 65** | 32900 | 23000 | | 29000 | Assumes 100% oil; distance between platforms not given |

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